# ECONOMIC GEOLOGY

## e – Learning Material: Unit-1

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# ORE AND GANGUE MINERALS

**Economic Geology** is an important branch of Geology which deals with different aspects of economic minerals being utilized by mankind to fulfill his various needs

**Economic Minerals** are those which can be extracted profitably

**This subject deals with**

- Minerals and their origin
- Processes of mineral formation
- control of localization
- Metalogenic epoch and provinces, etc.

# What is a mineral?

**A solid naturally-occurring compound having a definite chemical composition**

**Examples:**

**quartz – $SiO_2$ (an oxide)**

**hematite – $Fe_2O_3$ (another oxide)**

**chalcopyrite – CuFeS (a sulphide)**

# MINERAL DEPOSITS

The term Mineral Deposit refers to any accumulation of useful minerals of the mineral kingdom.

Such deposit may be classified as metalliferous (Copper, lead) or non-metallic (Bauxite)

The elements that enter into the constituents of the mineral deposits are derived either from the rocks of the earth crust or from the molten bodies (magma)

**Metallic Mineral Deposit:** The concentration of metals in the deposit is called Metallic Mineral Deposit. These metals generally associated with other elements such compounds are said to be ore minerals

**Non-Metallic Deposits:** The non-metallic deposits consist of solids, liquids and gases.

The term ‘ore’ is not generally used to refer such deposits. They called by the name of the substance itself such as Mica, Petroleum, Coal, Asbestos

The unwanted material is simply called as ‘Waste’ and not as gangue

The price is generally low compare to metallic deposit, they are common substances

Except Gemstones, most of the non-metallic deposits are free of waste or little waste

Feldspar, Barite, etc. have a considerable waste

# What is an ore?

**An occurrence of minerals or metals in sufficiently high concentration to be *profitable* to mine and process using *current technology* and under *current economic conditions*.**

A high grade lead deposit in Antarctica may not considered as ore at present, since it can not be commercially utilized

To be an Ore, there are two factors

1) The cost of production and 2) the market value

Single ores contain a single metal and complex ore (ore minerals) consist of more than one metal

Molybdenum – single metal in Molybdenite

Chalcopyrite – Copper association with Iron and Sulphur

Most ore minerals are combinations of metals with sulphur, oxygen and other non-metals

Some metals like gold, plattinam, copper are occur in native form

Single metals may form many ore minerals or single metal can be extracted from the number of ore minerals.

For example:- Copper

as a native metal – Cuprite

as a Silicate – Chrysocolla

as a Sulphides – Chalcopyrite, bornite, covellite, chalcocite

as a Carbonates – Malachite, azurite

**Gangue:** The ore minerals are usually associated with non-metallic materials or rock forming silicates which are not desired . These unwanted materials are called as Gangue

**Gangue** is mainly composed of rock forming minerals like Quartz, feldspar, Calcite

However, certain gangue minerals are collected as byproducts and utilized. For example: rock Gangue may be utilized as road metal, fluorspar and limestone as flux, quartz as abrasive, pyrite for manufacturing sulphuric acid

**The tenor of ore is the metal content of the ore. Which is required to give profit**

**The tenor is usually expressed as**

- **Weight percentage (base metals)**
- **Grams/tonne (precious metals)**

**The tenor varies with the**

**Price of the metal , cost of production, ores of different metals, different ores of same metals**

**The Higher price of the metal, the lower the metal content is required to make it profitable**

**Most of the iron ore is profitable – tenor of 35 – 50%**

**The tenor of copper is 0.8%**

**Gold 1/1000 of 1 %**

# Economically Important Metal Concentrations in Earth's Crust

| Metal | Concentration (% by weight) |
|---|---|
| Aluminum | 8.0 |
| Iron | 5.8 |
| Copper | 0.0058 |
| Nickel | 0.0072 |
| Zinc | 0.0082 |
| Uranium | 0.00016 |
| Lead | 0.001 |
| Silver | 0.000008 |
| Gold | 0.0000002 |

**Note for comparison:**
**Silicon 28%**
**Oxygen 46%**

# Mineral Resources

**'Mineral Resource' is a concentration or occurrence of material of intrinsic economic interest in or on the Earth's crust in such form and quantity that there are reasonable prospects for eventual economic extraction.**

**The location, quantity, grade, geological characteristics and continuity of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge. Mineral Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories.**

- ***Inferred***: That part of a Mineral Resource for which tonnage, grade and mineral content can be estimated with a low level of confidence.
- ***Indicated***: That part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a reasonable level of confidence
- ***Measured***: That part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a high level of confidence.

# Mineral Resources and Ore Reserves

An **'Ore Reserve'** is the economically mineable part of a Measured or Indicated Mineral Resource. It includes diluting materials and allowances for losses which may occur when the material is mined.

Appropriate assessments, which may include feasibility studies, have been carried out, and include consideration of metallurgical, economic, marketing, legal, environmental, social and governmental factors.

These assessments demonstrate at the time of reporting that extraction could reasonably be justified. Ore Reserves are sub-divided in order of increasing confidence into Probable Ore Reserves and Proved Ore Reserves .

# Mineral Resources and Ore Reserves

A **'Probable Ore Reserve'** is the economically mineable part of an Indicated, and in some circumstances Measured Mineral Resource.

**A Probable Ore Reserve has a lower level of confidence than a Proved Ore Reserve.**

A **'Proved Ore Reserve'** is the economically mineable part of a Measured Mineral Resource. It includes diluting materials and allowances for losses which may occur when the material is mined. Appropriate assessments, which may include feasibility studies, have been carried out, and include consideration of and modification by realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting that extraction could reasonably be justified.

# RESERVES

- ***Probable***: The economically mineable part of an Indicated and, in some circumstances, Measured Mineral Resource.

- ***Proven***: The economically mineable part of a Measured Mineral Resource.

# Mineral Resources and Ore Reserves

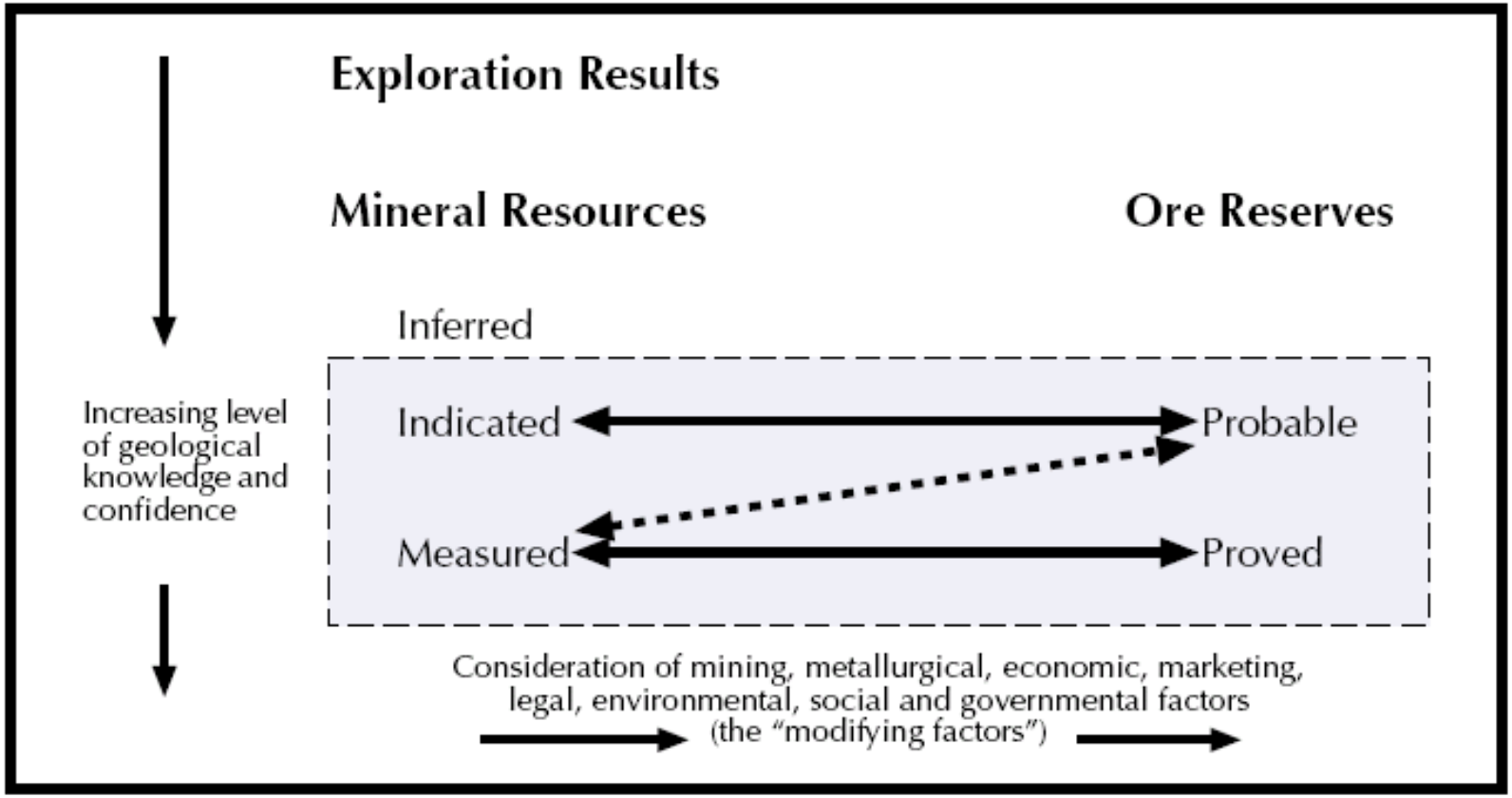



**Figure 1. General relationship between Exploration Results, Mineral Resources and Ore Reserves**

# SOME OF THE IMPORTANT ORES AND OREMINERALS



TABLE 2.1 Some of the more important ores and ore minerals.

| Commodity and principal ore minerals | Mineral formulae | % Metal | Primary | Supergene | Remarks | Major uses |
|---|---|---|---|---|---|---|
| Aggregates | | | | | Many different rocks and minerals used | Civil engineering, building |
| Antimony | | | | | Often a byproduct of base metal mining | Alloys |
| stibnite | $Sb_2S_3$ | 72 | X | | | |
| tetrahedrite | $(Cu,Fe)_{12}Sb_4S_{13}$ | 36 | X | | | |
| jamesonite | $Pb_4FeSb_6S_{14}$ | 33 | X | | | |
| Arsenic | | | | | Normally a byproduct of metal mining | Herbicide, alloys, wood preservative |
| arsenopyrite | FeAsS | 46 | X | | | |
| enargite | $Cu_3AsS_4$ | 19 | X | | | |
| löllingite | $FeAs_2$ | 73 | X | | | |
| tennantite | $(Cu,Fe)_{12}As_4S_{13}$ | 13 | X | | | |
| Asbestos | | | | | Dangerous materials, usage declining | Insulation |
| chrysotile | $(Mg,Fe)_3Si_2O_5(OH)_4$ | | X | | | |
| riebeckite | $Na_3(Fe,Mg)_4FeSi_8O_{22}(OH)_2$ | | X | | | |
| Baryte | $BaSO_4$ | | X | | | Drilling muds, filler |
| Bauxite | | ≈39 | | | Industrial mineral uses increasing | Aluminum production |
| boehmite | AlO(OH) | | | X | | |
| diaspore | AlO(OH) | | | X | | |
| gibbsite | $Al(OH)_3$ | | | X | | |
| Bentonite and fuller's earth | Montmorillonite group minerals | | X | X | | Bleaching clays, drilling muds, binders |
| | | | X | X | | |
| Beryllium | | | | | Bertrandite is now more important than beryl | Alloys, electronics |
| bertrandite | $Be_4Si_2O_7(OH)_2$ | | X | | | |
| beryl | $Be_3Al_2Si_6O_{18}$ | | X | | | |
| Bismuth | | | | | A byproduct of various metal mining operations | Pharmaceutical industry, alloys |
| bismuthinite | $Bi_2S_3$ | 81 | X | | Various unusual minerals | |
| Borates | | | X | | | Glass wool, borosilicate glasses, detergents, agriculture |
| Chromium | | | | | | Depends on Cr *v.* Al content. Steel industry, refractories, chemicals |
| chromite | $(Fe,Mg)(Cr,Al)_2O_4$ | 68(Cr) | X | | | |
| Coal | C,O&H | | X | | | Energy source |
| Cobalt | | | | | Byproduct of some copper mines | High temperature alloys, magnets, tool steels |
| carrollite | $CuCo_2S_4$ | 56 | X | | | |
| cobaltiferous pyrite | $(Fe,Co)S_2$ | Variable | X | | | |
| Common clay | See shale | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Copper | | | | | Many other ores of copper | Copper production |
| bornite | $Cu_5FeS_4$ | 63 | X | | | |
| chalcocite | $Cu_2S$ | 80 | X | X | | |
| chalcopyrite | $CuFeS_2$ | 34 | X | | | |
| covellite | CuS | 66 | X | X | | |
| Diamond | C | | X | | Considerable production of synthetic and industrial diamonds | Jewellery, cutting and grinding tools |
| Diatomite | $SiO_2.nH_2O$ | | X | | | Filters, filler, abrasive |
| Feldspar | $NaAlSi_3O_8$ | | X | | | Ceramics, glass making |
| | $KAlSi_3O_8$ | | X | | | |
| Fluorspar | $CaF_2$ | | X | | Fluorspar is the raw ore, fluorite the pure mineral | Flux in steel making, fluorochemicals |
| Gold | | | | | Many other tellurides may occur in gold ores | Jewellery, hoarding, dentistry |
| native gold | Au | 90–100 | X | | | |
| calaverite | $AuTe_2$ | 39 | X | | | |
| sylvanite | $(Au,Ag)Te_2$ | variable | X | | | |
| Graphite | C | | X | | | Steel making, refractories, foundries |
| Gypsum | $CaSO_4.2H_2O$ | | X | | | Plasterboard, insulation |
| Iron | | | | | | Iron production |
| hematite | $Fe_2O_3$ | 72 | X | X | | |
| magnetite | $Fe_3O_4$ | 70 | X | | | |
| siderite | $FeCO_3$ | 48 | X | X | | |
| Kaolin | | | | | A constituent of many clays: ball clay, refractory clay, etc. | Paper manufacture, coating clay, filler, extender |
| kaolinite | $Al_4Si_4O_{10}(OH)_8$ | | X | X | | |
| Limestone | $CaCO_3$ | | X | | One of the world's most widely used materials | Constructional, agricultural, chemical and metallurgical industries |
| Lithium | | | | | Li brines are now important producers | Ceramics, glass, enamels, Li salts, Li chemicals, batteries |
| amblygonite | Li | | | | | |
| lepidolite | $K(LiAl)_3(Si,Al)_4O_{10}(F,OH)_2$ | | X | | | |
| petalite | $LiAlSi_4O_{10}$ | | | | | |
| spodumene | $LiAlSi_2O_6$ | | | | | |
| Lead | | | | | Galena may be argentiferous | Lead production |
| galena | PbS | 86 | X | | | |
| Magnesite | $MgCO_3$ | | X | | Marketed mainly as magnesia | Refractories, animal feedstuffs, special cements |

TABLE 2.1 (continued)

| Commodity and principal ore minerals | Mineral formulae | % Metal | Primary | Supergene | Remarks | Major uses |
|---|---|---|---|---|---|---|
| Manganese | | | | | Most important | Steel making. Over 1 Mt |
| pyrolusite | $MnO_2$ | 63 | X | X | ferro-alloy metal | p.a. is used for industrial |
| psilomenane | $(BaMn)Mn_4O_8(OH)_2$ | 50 | X | X | | mineral purposes |
| braunite | $Mn_7SiO_{12}$ | 64 | X | X | | |
| manganite | MnO.OH | 62 | X | X | | |
| Mercury | | | | | | Mercury production |
| cinnabar | HgS | 86 | X | | | |
| Mica | | | | | Marketed as sheet | Electrical insulator, |
| muscovite | $KAl_2(AlSi_3O_{10})(OH)_2$ | | X | | or ground mica | furnace windows, |
| phlogopite | $KMg_3(AlSi_3O_{10})(F,OH)_2$ | | | X | | wallpaper, paints, plasterboard |
| Molybdenum | | | | | Mined as the principal | Molybdenum production |
| molybdenite | $MoS_2$ | 60 | X | | metal or as a byproduct | |
| wulfenite | $PbMoO_4$ | 26 | X | | | |
| Nepheline–syenite and sheet | | | | X | Composed of nepheline, albite and microcline | Container glass, whitewares, glazes |
| Nickel | | | | | | Nickel production |
| pentlandite | $(Fe,Ni)_9S_8$ | 28(max) | X | | | |
| garnierite | $(Ni,Mg)_3Si_2O_5(OH)_4$ | <20 | | X | | |
| Perlite | Rhyolitic composition | | X | | A volcanic glass that expands on heating | Insulation board, plaster, concrete |
| PGM | | | | | Several other PGM | Catalysts, electrical |
| nat. platinum | Pt | ≈100 | X | | minerals may be present | industry, jewellery |
| sperrylite | $PtAs_2$ | 57 | X | | in ores | |
| braggite | (Pt,Pd,Ni)S | variable | X | | | |
| laurite | $(Ru,Ir,Os)S_2$ | variable | X | | | |
| Phosphate rock | | | | | | Fertilizer (90%), |
| apatite | $Ca_5(PO_4)_3(F,OH)$ | P = 18 | X | X | | detergents, animal feedstuffs |
| Pyrophyllite | $Al_2Si_4O_{11}.H_2O$ | | X | | | Ladle linings in steel mills, ceramics, insecticides |
| Potash | | | | | | About 95% goes into |
| sylvite | KCl | | X | | | fertilizer manufacture, |
| carnallite | $KCl.MgCl_2.6H_2O$ | | X | | | rest for soaps, glass, |
| kainite | $4KCl.4MgSO_4.11H_2O$ | | X | | | ceramics, etc. |
| langbeinite | $K_2SO_4.2MgSO_4$ | | X | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| REE | | | | | Many more REE in these minerals than shown in formulae | Catalysts, glass, ceramics, television tubes, permanent magnets, etc. |
| bastnäsite | $(Ce,La)(CO_3)F$ | | X | | | |
| parisite | $(Ce,La)_2Ca(CO_3)_3F_2$ | | X | | | |
| monazite | $(Ce,La,Nd,Th)PO_4$ | | X | | | |
| Salt | | | | | | Innumerable! Over half of all production used in the chemical industry, deicing agent, food preservative |
| halite | NaCl | | X | | | |
| Shale and tiles, sewer common clay | Clay and mica minerals, quartz | | | X | 60–80% of all "clay" mined falls into this category | Bricks, pipes, cement, lightweight aggregate |
| Silica sand | $SiO_2$ | | | | Sand and gravel working taken worldwide represents one of the most important mining industries | Building, civil engineering, glass manufacture |
| Sillimanite minerals | | | | | | Refractories account for 90% of production |
| andalusite | $Al_2SiO_5$ | | X | | | |
| kyanite | $Al_2SiO_5$ | 100 | X | | | |
| sillimanite | $Al_2SiO_5$ | $Ag_2S$ | X | | | |
| Silver | | | | | Byproduct of many base metal mines particularly Pb-Zn tetrahedrite and many other minerals | Photography, electrical and electronic industries, sterling ware, jewellery, etc. |
| nat. silver | Ag | | X | X | | |
| acanthite | | 75 | 87 | X | | |
| argentiferous tetrahedrite | $(Cu,Fe,Ag)_{12}Sb_4S_{13}$ | | X | | | |
| cerargyrite and many other minerals | AgCl | | X | | | |
| Sodium carbonate | | | | | Bulk of soda ash is (trona) produced synthetically in Solvay plants | Production of soda ash, $Na_2CO_3$, for glass manufacture, sodium chemicals, paper production, etc. |
| trona | $Na_2CO_3.NaHCO_3.2H_2O$ | | | | | |
| Strontium minerals | | | | | Celestite is the only economically important Sr mineral. Used in industry as $SrCO_3$ | Pyrotechnics, color TV tubes, permanent magnets, greases, soaps |
| celestite | $SrSO_4$ | | X | | | |
| | | 100 | | | | |
| Sulphur | | | | | Main source is crude oil. | Sulfuric acid production, fertilizers, etc. |
| nat. sulphur | S | | X | X | Native sulfur 30%, pyrite 16% | |
| pyrite | $FeS_2$ | | | | | |
| Talc | | | | | Has very many important uses | Filler in paints, plastics, paper, rubber, porcelain, tiles, cosmetics |
| talc | $Mg_3Si_4O_{10}(OH)_2$ | 78 | X | | | |
| | | 27 | | | | |
| Tin, cassiterite | $SnO_2$ | | X | | Cassiterite is the main ore mineral | Solder, tin-plate, alloys, etc. |
| stannite | $Cu_2FeSnS_4$ | | X | | | |

TABLE 2.1 (continued)

| Commodity and principal ore minerals | Mineral formulae | % Metal | Primary | Supergene | Remarks | Major uses |
|---|---|---|---|---|---|---|
| Titania | | | | | Both an important metal and industrial material in form $TiO_2$ | White pigment in paint, plastics, rubber, paper, etc. |
| ilmenite | $FeTiO_3$ | $TiO_2$ = 45–65 | X | | | |
| rutile | $TiO_2$ | $TiO_2$ = 90–98 | | X | | |
| Tungsten | | | | | | Cutting materials, steels, electric light bulbs |
| scheelite | $CaWO_4$ | 64 | X | | | |
| wolframite | $(Fe,Mn)WO_4$ | 61 | X | | | |
| Uranium | | | | | Many other ore minerals | Nuclear-powered generators, special steels, military purposes |
| uraninite-pitchblende | $UO_2$ | 88 | X | | | |
| uranophane | $Ca(UO_2)_2Si_2O_7.6H_2O$ | 56 | | X | | |
| carnotite | $K_2(UO_2)_2(VO_4)_2.3H_2O$ | 55 | X | X | | |
| torbernite | $Cu(UO_2)_2(PO_4)_2.8H_2O$ | 51 | X | X | | |
| Vanadium | | | | | The main producer is now the RSA from Ti–V–magnetites in the Bushveld Complex | Vanadium steels, super alloys |
| carnotite | $K_2(UO_2)_2(VO_4)_2.3H_2O$ | 13 | X | X | | |
| tyuyamunite | $Ca(UO_2)(VO_4)_2.5\text{-}8H_2O$ | 15 | X | X | | |
| montroseite | VO(OH) | 61 | X | | | |
| roscoelite | vanadium mica | | X | | | |
| magnetite | $(Fe,Ti,V)_2O_4$ | V = 1.5–2.1 | X | | | |
| Vermiculite | $(Mg,Fe,Al)_3(Al,Si)_4O_{10}(OH)_2.4H_2O$ | | X | X | Expands on heating | Acoustical and thermal insulator, carrier for fertilizer and agricultural chemicals |
| Wollastonite | $CaSiO_3$ | | X | | | Ceramics, filler, extender |
| Zeolites | | | X | | Uses multiplying rapidly, much of the demand supplied by synthetic zeolites | Cements, paper filler, ion exchange resins, dietary supplement for animals, molecular "sieve", catalyst |
| Zinc | | | | | | Alloy castings, galvanizing iron and steel, copper-based alloys, e.g. brass |
| hemimorphite | $Zn_4(OH)_2Si_2O_7.H_2O$ | 54 | | X | | |
| smithsonite | $ZnCO_3$ | 52 | | X | | |
| sphalerite | (Zn,Fe)S | up to 67 | X | | | |
| Zirconium | | | | | Most zircon is converted to $ZrO_2$ for industrial use | Refractories, foundry sands, nuclear reactors |
| baddeleyite | $ZrO_2$ | 74 | X | | | |
| zircon | $ZrSiO_4$ | 50 | X | | | |

TABLE 2.2 List of common gangue minerals.

| Name | Composition |
|---|---|
| Quartz | $SiO_2$ |
| Chert | $SiO_2$ |
| Limonite | $Fe_2O_3.nH_2O$ |
| Calcite | $CaCO_3$ |
| Dolomite | $CaMg(CO_3)_2$ |
| Ankerite | $Ca(Mg,Fe)(CO_3)_2$ |
| Baryte | $BaSO_4$ |
| Gypsum | $CaSO_4.2H_2O$ |
| Feldspar | All types |
| Fluorite | $CaF_2$ |
| Garnet | Andradite most common |
| Chlorite | Several varieties |
| Clay minerals | Various |
| Pyrite | $FeS_2$ |
| Marcasite | $FeS_2$ |
| Pyrrhotite | $Fe_{1-x}S$ |
| Arsenopyrite | FeAsS |

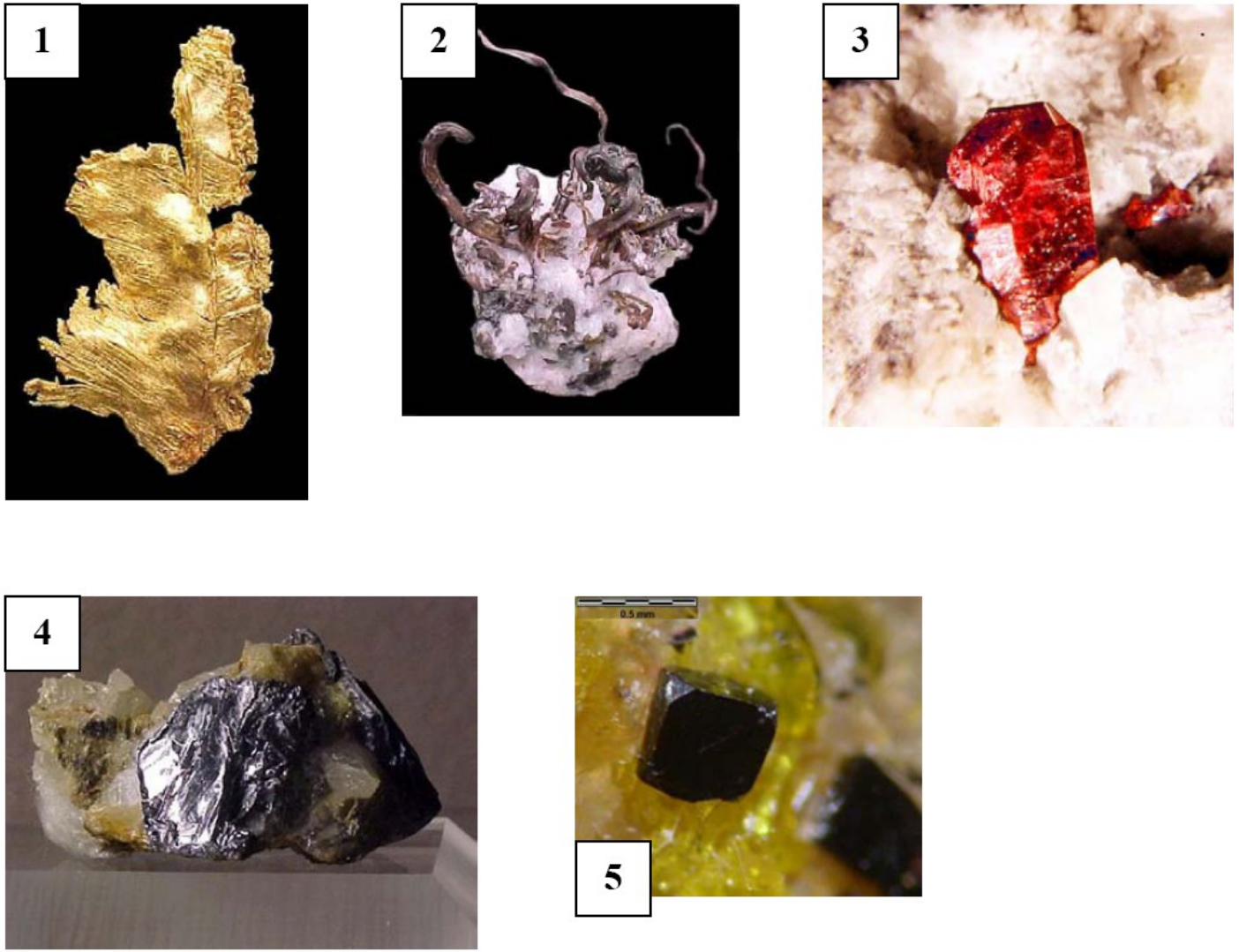



Figure 1: Examples of important economic minerals. 1-gold; 2-silver; 3-cinnabar; 4-molybdenite; 5-uraninite. All images from http://webmineral.com/specimens/picshow.php?id=1478

# Formation of Mineral Deposits

# PRIMARY OR HYPOGENE AND SECONDARY OR SUPERGENE

Ore minerals may be divided into primary or hypogene and secondary or supergene minerals

Primary or hypogene minerals are those which form during the original periods of metallisation

The supergene or secondary minerals are formed by the alteration of the former by weathering or by other surficial processes resulting from descending surface water

Hypogene minerals are formed by ascending fluids

# Formation of Mineral Deposits

Endogenous Processes (Primary or Hypogene)

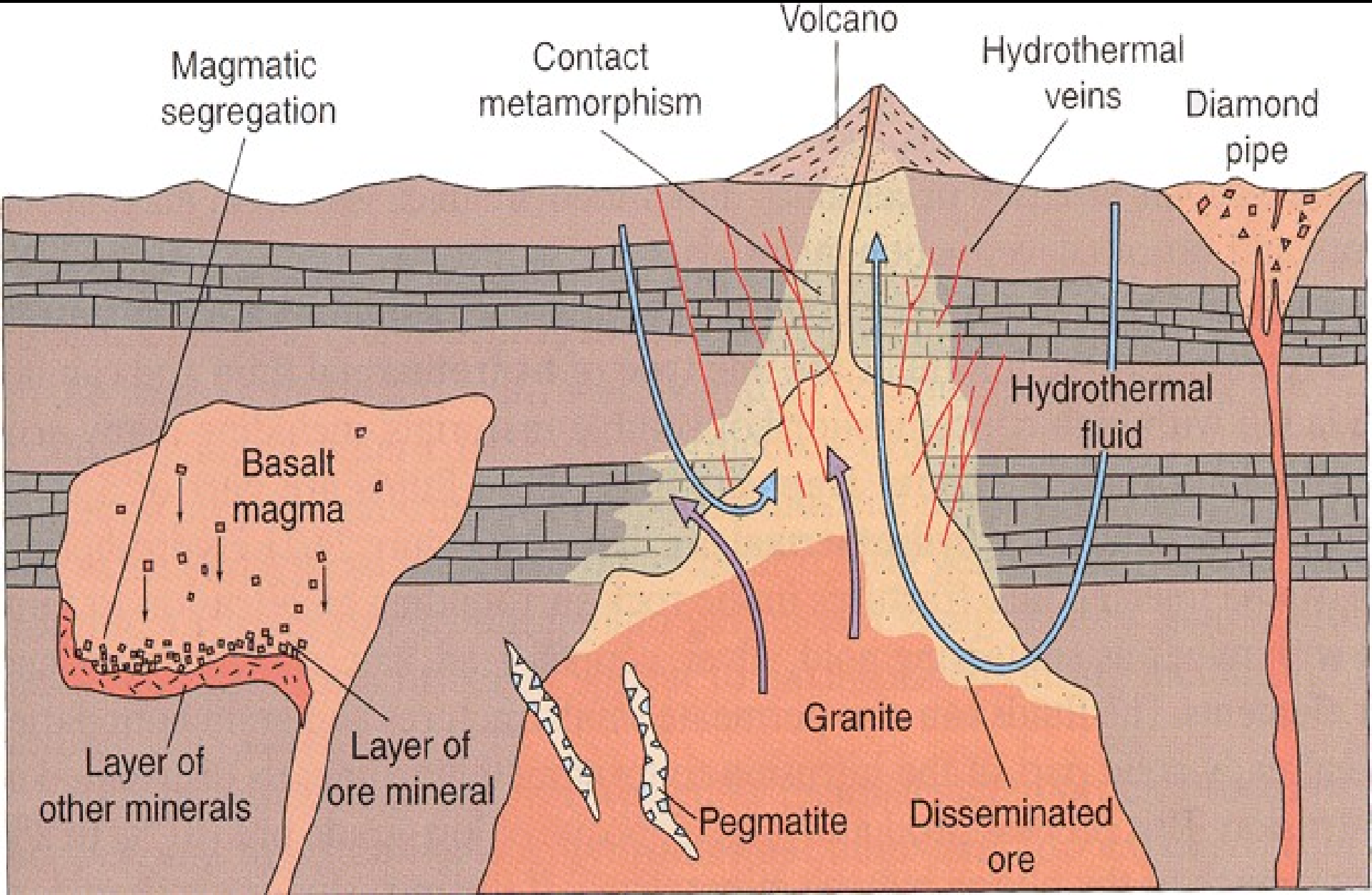
- Magmatic concentration
- Metamorphism/Metasomatism
- Hydrothermal process

Exogenous Processes (**Secondary or supergene)**

- Weathering & Supergene enrichment
- Chemical deposition
- Mechanical concentration

| Process | Mineral deposit | mineral/energy resource |
|---|---|---|
| ***Magmatic processes***<br>1) segregation by settling<br>2) fractional crystallization | 1) chromite deposits in layered intrusions<br>2) pegmatites | 1) chromium, vanadium, nickel, copper, cobalt, platinum<br>2) beryllium, lithium, tantalum |
| ***Sedimentary processes***<br>1) precipitation (chemical)<br>2) precipitation (organic)<br>3) flowing water<br>4) wind | 1) evaporites. oolites, iron deposits<br>2) phosphorites, hydrocarbon, limestone<br>3a) placer<br>3b) stream deposits<br>4a) dune<br>4b) loess | 1) halite, sylvite, borax, gypsum, trona, BIF<br>2) phosphate, oil, coal, limestone<br>3a) gold, platinum diamonds, tin, ilmenite, rutile, zircons<br>3b) sand and gravel<br>4a) sand 4b) soil |
| ***Weathering / Ground water*** | residual soils<br>residual weathering deposits<br>groundwater deposits<br>brines<br>geothermal wells<br>water | clay<br>nickel, iron, cobalt, aluminum, gold<br>travertine, uranium, sulfur<br>lead, zinc, copper<br>hot water, electricity<br>drinking water, irrigation |
| ***Metamorphic processes*** | contact metaqmorphism<br>regional metamorphism | tungsten, copper, tin, lead, zinc, gold, silver<br>gold, tungsten, copper, talc, asbestos |
| ***Hydrothermal processes***<br>(e.g. black smokers) | hydrothermal deposits | copper, lead, zinc, molybdenum, tin, gold, sliver |

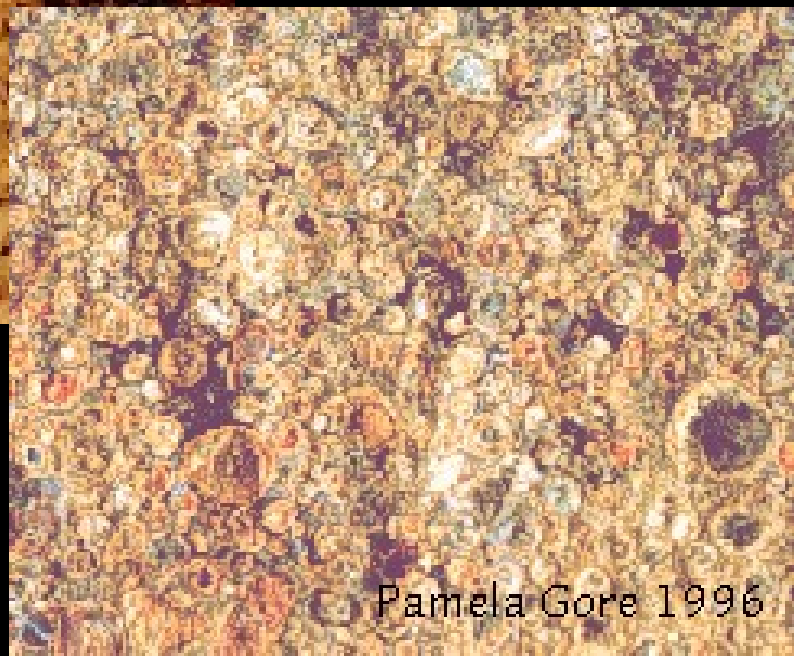
# Endogenous Processes of Ore Formation



# Exogenous Processes of Ore Formation

- Weathering/Supergene Enrichment
- Chemical Deposition
- Mechanical Concentration

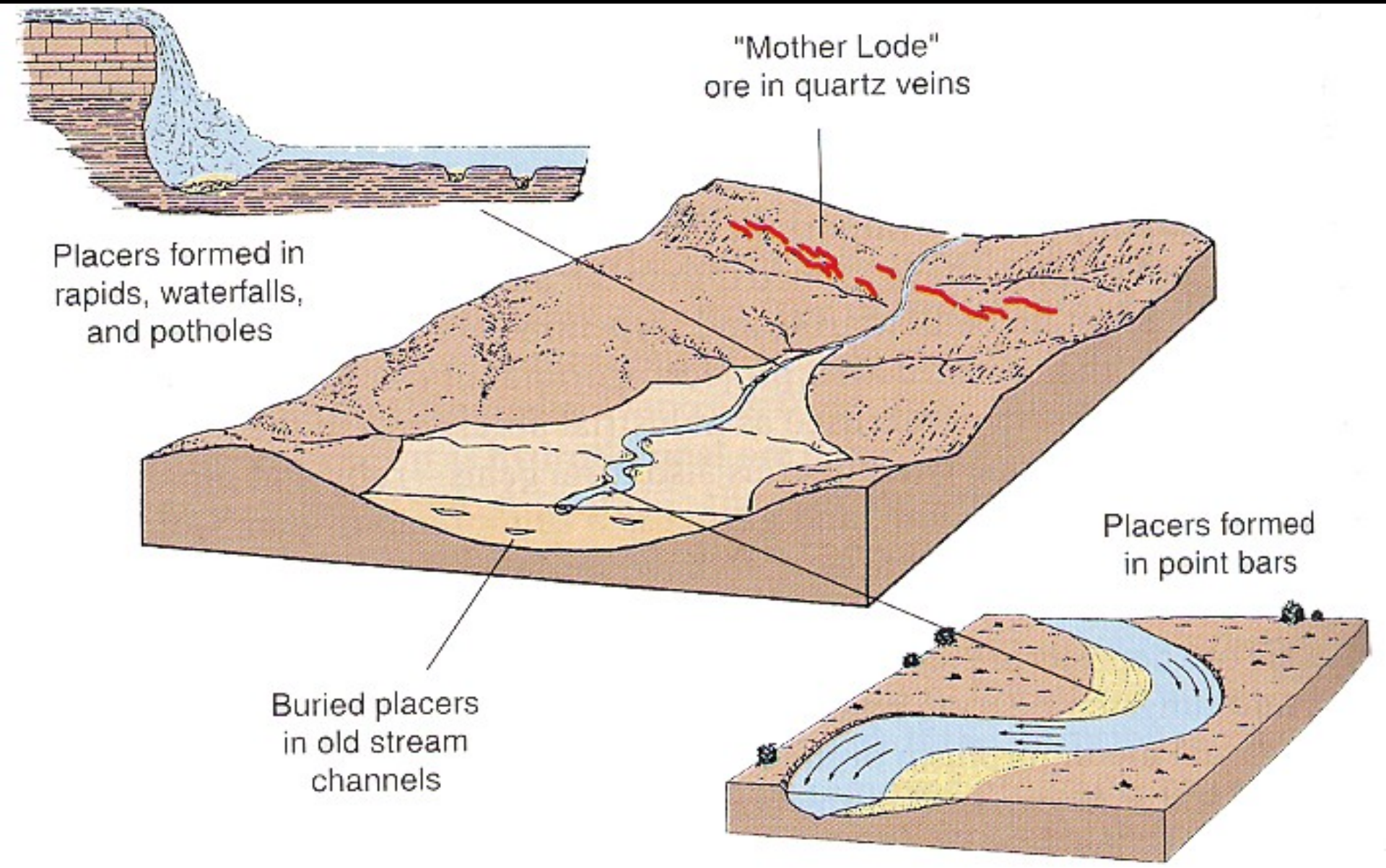

Bauxite




Weathering

# Chemical Deposition

# Mechanical Concentration



# THE FORMATION OF MINERALS AND MINERAL DEPOSITS

To have a better understanding of mineral deposits, it is important that how mineral deposits are formed

The formation of a mineral generally involves a change from a mobile to solid state

Since most of the mineral deposit from solutions, the temperature and pressure play important roles

In general decrease of temperature and pressure promote precipitation from aqueous solutions and magmas

The mineral deposits formed in several ways, the important of which are discussed

# Crystallization from Magmas

Magma is a molten fluid which form igneous rocks on cooling

It is composed of mutual solutions of silicates, silica, metallic oxides, sulphides and volatile substances

The temperature of magma varies from $600^0$ C to $1250^0$C

When magma cools the saturation point of certain minerals may be reached and if the temperature of the magma is below the fusion point of these minerals tend to crystallise

For example: Apatite, Magnetite, Chromite, diamond, platinum, etc. have formed from by crystallization

## Sublimation

Certain substances like sulphur are readily volatilised by the heat of igneous activity

These substances may be deposited when the vapour is cooled around the vents of volcanoes, fumaroles without passing into liquid state. This is called **Sublimation**

## Distillation

It is believed that petroleum and natural gas are formed by the slow distillation of organic matter buried with sediments at the considerable depth

## Evaporation and Supersaturation

Salts in solution are deposited when evaporation brings about supersaturation. Ex. Salt deposition from brines and the deposition of sulphate of copper, iron, zinc, calcium, etc.

## Reaction of gases with other gases

Igneous activity is accompanied by large quantities of gaseous emanations that contain the elements and compounds of mineral deposits.

Reaction between different gases and vapours result in the precipitation of metals and other substances contained in them

For example: native sulphur and hematite formation

$2H_2S + SO2 = 3S + H_20$

$Fe_2CL6 + 3H_20 = Fe_2O_3 + 6HCL$

# Salt mine from Sal Island

## Reaction Between Gases and Solids

The magmatic gases react with the intruded rocks particularly carbonate rocks and produce complex mineral assemblages and same way reaction between gases and liquids at high and normal temperatures

Example: Precipitation of Copper sulphides from Cupric sulphate

## Reaction of Liquids with Liquids and solids

Consolidating magmas may give off enormous quantities of magmatic fluids which are rich in minerals. These solution are liquids and responsible for formation of many deposits

During their ascent journey they may meet surface waters of different composition or other magmatic fluids and wall rock of varying composition and react with them and result in the precipitation of minerals

These reaction took place through various processes such as Metasomatism, Solubility, Reduction and Oxidation

## a) Metasomatic Replacement

It is a process by which a substance is removed in solution and simultaneously a new substance is deposited in its place. It is also known as replacement

Replacement is the most important process in the formation of epigenetic deposits example: Copper sulphate in solution may replace limestone to form copper carbonate or pyrite to chalcocite

## b) Relative solubility of solid and solute

Determines the precipitation of many minerals from solution. For example: if copper sulphate solution comes into contact with sphalerite (ZnS) which is more soluble, copper sulphide will be precipitated at the expense of sphalerite. But the reverse is not possible

## c) Reduction and Oxidation

Reduction and Oxidation may also cause precipitation of minerals when a solution contacts a solid

For example: Gold is reduced from cupriferous solutions by pyrite or organic matter. Native copper is deposited when cupriferous solutions are oxidised by ferric iron

Oxidation of pyrite yields limestone

## Deposition In Open Spaces

When a solution comes into contact with a solid the materials contained in it may be simply deposited in the open space by changes in temperature and pressure without any replacement

Certain types of wall rocks also favor precipitation by reaction

## Catalytic Action

There are certain mineral substances which cause the precipitation of mineral matter from solutions without themselves entering into the solution

## Base Exchange

Occurs between solids and liquids whereby cations of similar size are exchanged producing new minerals

## Precipitation by Bacteria

It has been established that many iron ore deposits have precipitated by soil bacteria

## Unmixing of Solid Solutions:

The term solid solution refers to the existence of more than one solid in a single homogenous phase

Among minerals many solid solutions are known such as solid solutions of gold and silver, magnetite and ilmentite, chalcocite and covelite, etc

Some solid solutions are stable at low temperature and others stable at high temperature

When temperature falls down at certain points such solid solutions are unstable and separate into their original constituents. **This is known as exsolution or unmixing**

**Thus ilmenite separate from magnetite, covelite laths from chalcocite**

## Colloidal Deposition:

Colloids are matter in a particular state. The colloidal solutions are two phase systems one is the continuous medium and generally liquid

The other is the discontinuous medium may be solid, liquid or gas and is disseminated in the other in minute particles but not in true molecular solutions.

Such systems are generally referred to as sols. If the dispersed phase is a solid, the sols are called suspensoid, if liquid is called emulsoids

The particles in sols are of submicroscopic size and in the same sol they carry similar electrical charges

Deposition of these particles is therefore brought by the addition of electrolytes carrying opposite charges

# Colloidal Deposition….

Colloids are readily precipitated from natural solutions as floculent or gelatinous masses

These floculent or gelatinous masses may harden to rounded or other colloform masses such as botryoidal, reniform, mamillary, nodular or pisolitic forms

The solidified colloids may persist in an amorphous state such as opal or they may acquire crystallinity such as marcasite, malachite or psilomelane

Thus many minerals are formed by colloidal precipitation

## Weathering and Mechanical Concentration Process

Weathering processes are very important in the formation of economic mineral deposits

Mechanical weathering does not create any new mineral but chemical weathering produces new minerals by acting upon the preexisting mineral deposits

Placers, mineral in alluvium, etc are the Mechanical concentration

## Metamorphism

Many economic minerals are produced by recrystallisation and recombination of the ingredients of the rocks during metamorphism. Example: Garnet, Graphite and Sillimanite

## Melting glaciers: sand and gravel

TABLE 2.1. Average abundances of selected ore-forming elements (in ppm) in the earth's continental crust, major rock types, and seawater (simplified from the compilation by Krauskopf and Bird 1995)

| Element | Crust (a) | Granite (b) | Diabase (c) (Basalt) | Shale | Seawater (d) |
|---|---|---|---|---|---|
| Al | 81,300 | 74,300 | 79,400 | 80,000 | 0.003 |
| Fe | 50,000 | 13,700 | 76,600 | 47,200 | 0.003 |
| Ti | 4,400 | 1,500 | 9,400 | 4,600 | 0.0001 |
| Mn | 950 | 195 | 1,280 | 850 | 0.0002 |
| S | 260 | 58 | 123 | 2,240 | 900 |
| C | 200 | 200 | 100 | 1,000 | 28 |
| V | 135 | 17 | 264 | 130 | 0.0022 |
| Cr | 100 | 20 | 114 | 90 | 0.0003 |
| Ni | 75 | 1 | 76 | 68 | 0.0005 |
| Zn | 70 | 45 | 86 | 95 | 0.0003 |
| Cu | 55 | 13 | 110 | 45 | 0.0002 |
| Co | 25 | 2.4 | 47 | 19 | $1 \times 10^{-6}$ |
| Pb | 13 | 48 | 7.8 | 20 | $3 \times 10^{-6}$ |
| U | 1.8 | 3.4 | 0.6 | 3.7 | 0.0032 |
| Sn | 2 | 3.5 | 3.2 | 6.0 | $6 \times 10^{-7}$ |
| Mo | 1.5 | 6.5 | 0.6 | 2.6 | 0.01 |
| W | 1.5 | 0.4 | 0.5 | 1.8 | 0.0001 |
| Hg | 0.08 | 0.1 | 0.2 | 0.4 | $4 \times 10^{-7}$ |
| Ag | 0.07 | 0.05 | 0.08 | 0.07 | $3 \times 10^{-6}$ |

Concentrations of Au and Pt are <0.05 ppm in rocks and <0.00001 ppm in seawater.
(a) "Crust" means the continental crust only, a part of the crust that is assumed to be made up of roughly equal parts of granite and basalt. For the oceanic crust a composition similar to that of average basalt can be assumed.
(b) "Granite" includes silica-rich rocks ranging from alkali granite to granodiorite and their volcanic equivalents.
(c) "Diabase" includes the more common varieties of basaltic lava, diabase, and dolerite.
(d) "Seawater" is an average analysis of deep Atlantic and deep Pacific water.

**Abundance of Elements in the Earth Crust**

# CLASSIFICATION OF MINERAL DEPOSIT

Classification of mineral deposits has been attempted by many authors, but none of them have been unanimously accepted.

The genetic classification is considered to be valuable for the working geologist, since it can be applied directly to the field

The earlier classification by Beck (1904), Bergsat and Steizner (1904) and Irving (1908) on the basis of origin.

# Classifications Based on Geological Processes

- Hydrothermal/Pegmatitic mineral deposits form in association with hot water- or gas-rich fluids
- Magmatic mineral deposits concentrated in igneous rocks;
- Metamoprhogenic mineral deposits concentrated by metamorhism / metasomatism
- Sedimentary mineral deposits are precipitated from a solution, typically sea water;

# Classifications Based on Host Lithology

- *Unconsolidated Deposits*
- *Sedimentary Rocks*
- *Volcanic Rocks*
- *Intrusive Rocks*
- *Regionally Metamorphosed Rocks*

I. Protogene (Primary)

A. Syngenetic

1. With eruptive rocks

2. With sedimentary rock

B. Epigenetic

1. Cavity filling

2. Replacement

II. Secondary

A. Residual

B. Placers

For example: Bergsat and Steizner (1904) classification

# Lindgren (1911) Classification

## Lindgren (1911) classified mineral deposits in two main sub-divisions

1)Those formed by mechanical concentration and

2)Those formed by chemical reaction in solutions

**The basis of this classification is the temperature and pressure of formation**

# Lindgren (1911) Classification

| | | |
|---|---|---|
| **A. In surface water** | **0 – 70 ° C** | **medium (pressure)** |
| 1. By reactions | | |
| 2. By Evaporation | | |
| **B. In bodies of rocks** | | |
| 1. Concentration of substances contained within rocks | | |
| a) By weathering | 0 – 100 ° C | Medium (Pressure) |
| b) By groundwater | 0 – 100 ° C | Medium |
| c) By metamorphism | 0 – 400 ° C | High |
| **2. By Introduced substances** | | |
| a) with out igneous activity | 0 – 100 ° C | Medium |
| b) related to igneous activity | | |
| 1. Epithermal deposits | 50 – 200 ° C | Medium |
| 2. Mesothermal deposits | 200 – 500+ ° C | High |
| 3. Hypothermal deposits | 500 – 600+ ° C | High |
| **c) By direct igneous emanation** | | |
| 1. Pyrometasomatic deposits | 500 – 800 ° C | High |
| 2. Sublimates | 100 – 600 ° C | Low to Medium |
| **C. In magmas by differentiation** | | |
| 1. Magmatic deposits | 700 – 1500 ° C | High |
| 2. Pegmatites | 575+ ° C | High |

Lindgren classification is most accepted genetic classification, but does not have the frame work for all kind of deposits. For example: deposit of native copper, regionally metamorphosed deposits, oxidation, supergene deposits, etc.

It consider mostly on temperature and pressure, but this is not in all cases

# Bateman's (1942) genetic classification based on the various processes of formation of mineral deposits

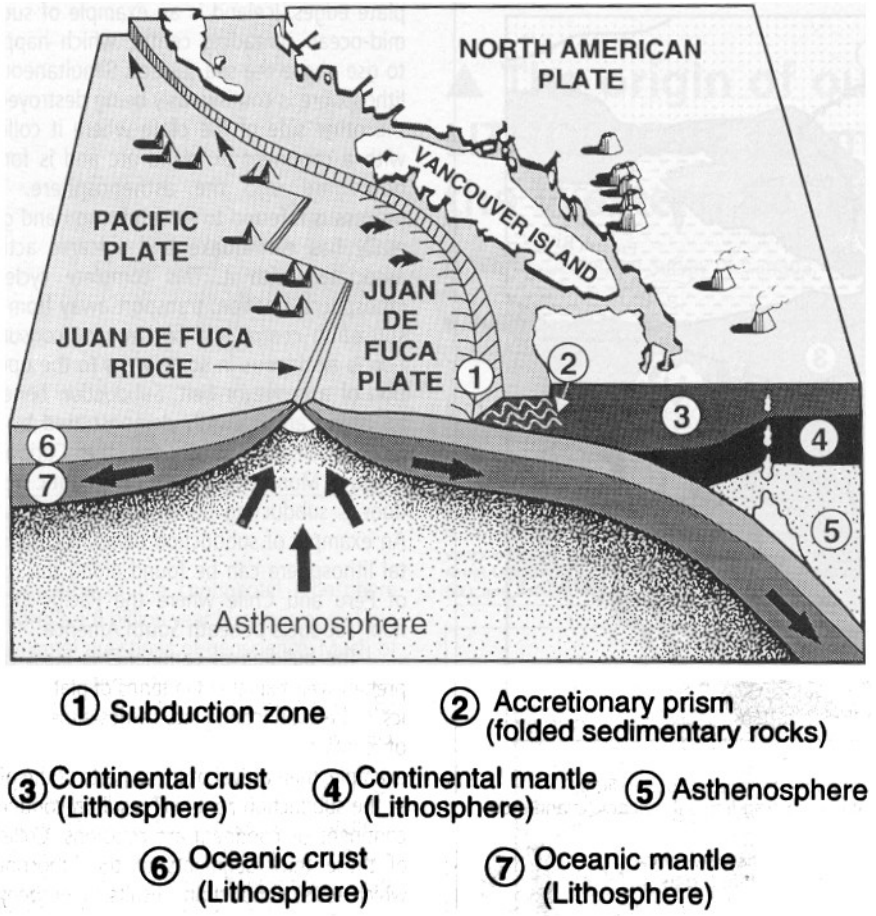
| Processes | Deposits |
| --- | --- |
| 1. Magmatic Concentration | a) Early magmatic – disseminated crystallization, segregation, injection |
| | b) Late magmatic – Residual liquid segregation, residual liquid injection. Immiscible liquid segregation and immiscible liquid injection |
| 2. Sublimation | Sublimate |
| 3. Contact metasomatism | Contact metasomatic |
| 4. Hydrothermal processes | a) Cavity filling |
| | b) Replacement |
| 5. Sedimentation | a) Sedimentary |

# Bateman's (1942) genetic classification based on the various processes of formation of mineral deposits….

| Processes | Deposits |
| --- | --- |
| 6. Evaporation | a) Evaporites |
| 7. Residual and Mechanical concentration | a) Residual deposits<br>b) Placers |
| 8. Surfacial oxidation and supergene enrichment | Oxidised, supergene sulphide |
| 9. Metamorphism | Metamorphosed and metamorphic deposit |

## On the basis of the analysis of several mineral deposit, Mitchell and Garson (1976) identified certain environment related to lithosphereic plates, conducive for the formation of mineral deposit

1. Ocean floor spreading
2. Subduction zones related
3. Collision related
4. Transform fault



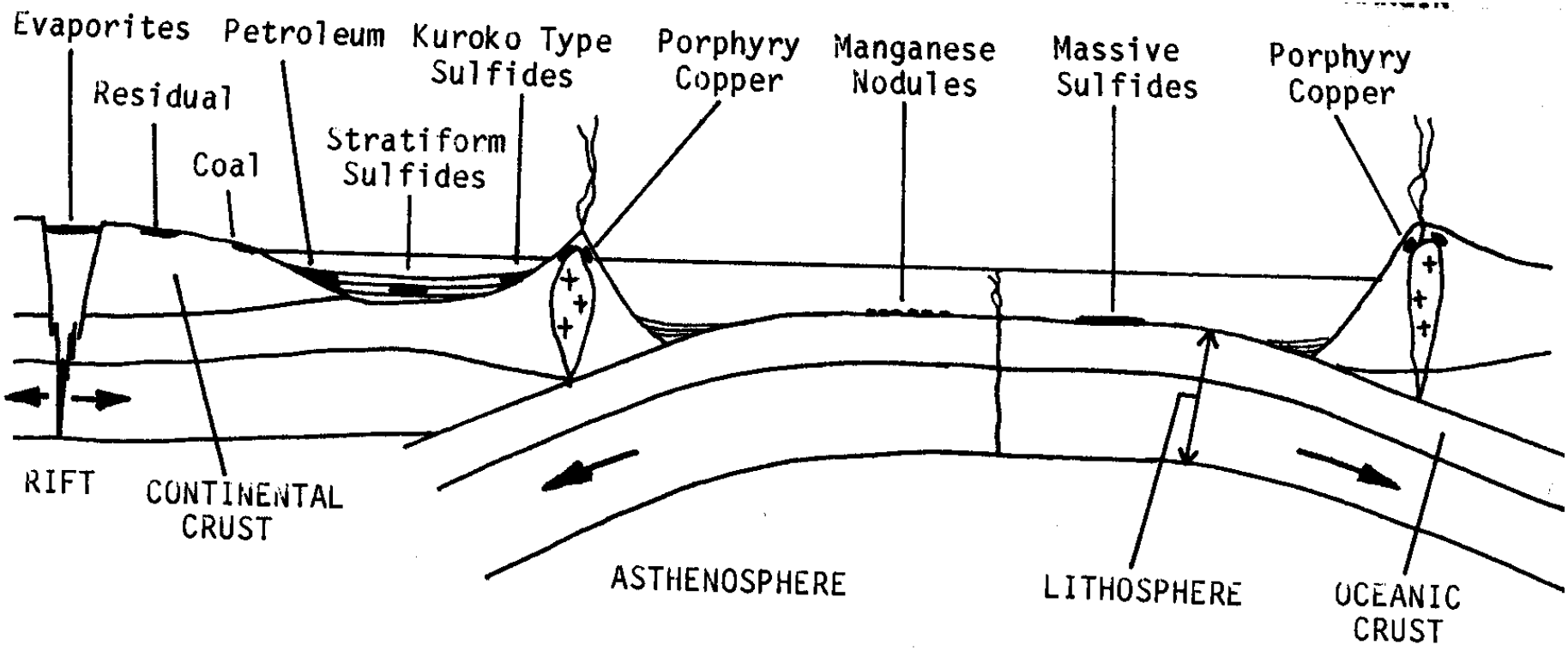



Figure 1.8: Suggested Relationships Between Some Mineral Deposits and the Main Elements of the Plate Tectonic Theory.

**The classification based on genesis is meant only for technocrats and is not of any commercial importance**

**Classification based on the nature and most prevalent use of minerals**

## A. Metallic Mineral Deposits

1. **Precious metals, e.g. gold, silver, platinum**
2. **Ferrous and Ferro-alloy metals e.g. iron, manganese**
3. **Non-ferrous and allied metals, e.g. copper, lead, etc.**
4. **Light metals, e.g. lithium, magnesium, etc.**
5. **Radio-active metals, e.g. uranium, thorium**
6. **Rare metals, e.g. palladium, selenium, etc.**

## 3. Non-Metallic Mineral Deposits

1. Mineral fuel, e.g. Coal, petroleum
2. Gemstones, e.g. diamond, ruby, etc.
3. Abrasive minerals, e.g. corundum, garnet, etc.
4. Building materials and the dimension stones e.g. marble, granite, etc.
5. Industrial Minerals, e.g. mica, asbestos, etc.
6. Refractory Minerals e.g. Fireclay, graphite, etc.
7. Glass manufacturing materials, e.g. quartz, silica, etc.
8. Ceramic minerals, e.g. clay, felspar,etc.
9. Fertilizer minerals, e.g. phosphorite, sulphur, etc.
10. Chemical minerals, e.g. rock salt, borax, etc.
11. Mineral pigments, e.g. ochre, umber, etc.
12. Mineral water and groundwater

# Ore Genesis

**Ore genesis deals with various attributes that provide direct or indirect evidence related to formation of ore deposits.**

**It is outcome of detailed studies involving geological, geochemical, petrological, isotopic and time-space relationship between ores and their repository set up.**

**The following attributes are important in understanding genesis of ore deposits:**

- Size and shape of repository basin.
- Tectonic setting of the basin.
- Structural relations between ore body and the host rock.
  - Stratiform
  - Stratabound
  - Cross-cutting relationships

It is often combination of more than one type of relationship.

- Recognition of primary relict structures.
- Remobilation of ores.
- Isotopic studies. Sulphur isotopes are used in estimating role of magmatic and seawater sulphates in the genesis of sulphides. Lead isotopic ratios $^{207}Pb/^{204}Pb$ are used for assessing source of metals.
- Fluid inclusion studies for determining salinity and temperature of formation of ore fluids.
- Recognition of distinctive lithological units.
- Geochemical indicators

- Timing of ore formation

Syngenetic vs Epigenetic

Age of ore deposit formation vs age of host or causative rock.

Dating of ores-Rb-Sr, Pb-Pb and Re-Os.

Magmatic deposits are thought to be consanguineous with the host rocks and their formation is linked with petrogenesis.

## Mineral Paragenesis and zoning, metallogenic epochs and provinces are the important factors of controls of mineral localization

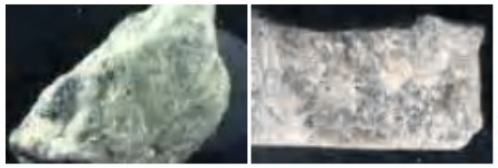
**Mineral Paragenesis:** The term mineral paragenesis defines the mutual relationships and time sequence of minerals

The individual minerals in mineral deposit of magmatic affiliations are formed in an orderly sequence and this sequential arrangement is termed paragenesis

The mineral paragenesis is identified by the field evidences and microscopic studies

# Bowen's Reaction Series

## And The Igneous Rock Forming Minerals



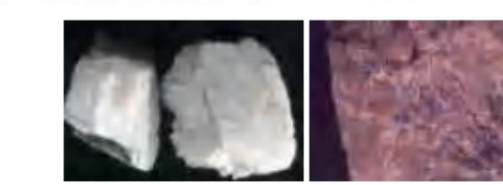
**Ferro-Magnesium (Mafic) Minerals**

light green, glassy, often as small grains → Olivine

dark green/black; dull blocky; 90° cleavage → Pyroxene

black, shiny, elongate, crystals, 60–120° cleavage → Amphibole

black, very shiny, in thin very smooth sheets → Biotite

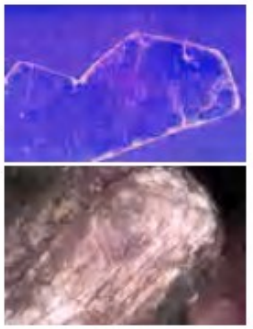


pink, white, greenish; two cleavages 90°; opaque → Orthoclase



→ Muscovite

white to brassy thin sheets; clear; very smooth



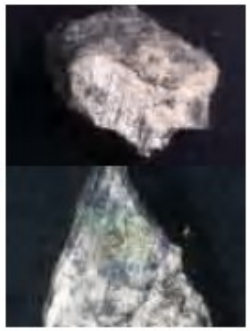
→ Quartz

glassy, clear, often appears gray in rocks; no cleavage

**Non-Ferro-Magnesium (Feldspar) Minerals**

Ca Plagioclase

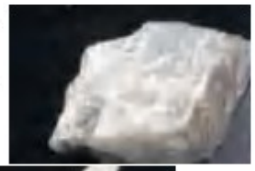
dark, almost black to light gray; 90° cleavage; striations and/or iridescence



increasing silicate

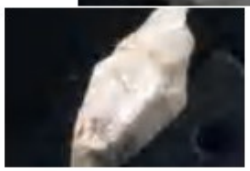
Ca/Na

white; 90° cleavage; striations sometimes; appears translucent



Na Plagioclase

white; 90° cleavage; striations sometimes; appears translucent



## Mineral Zoning

**Mineral zoning is the tendency for certain minerals or ores to be deposited at varying distances from a related focus of igneous activity**

**The higher temperature and least soluble minerals are found nearest the source**

**The low temperature and most soluble minerals are found farthest from source**

**Zoning in hydrothermal aureoles can also be classified according to direction. Zoning along the direction of flow of the ore-forming fluids is termed axial. Zoning outward from ore into wallrock, in a direction normal to the hydrothermal flow direction, is termed transverse.**

**Based on studies of a large number of deposits of different types, shows the following average sequence of metals**

Shallowest Deepest

Ba-(Sb, As, Hg)-Cd-Ag- Pb- Zn-Au-Cu-Bi-Ni-Co-Mo-U-Sn-Be-W

**At specific deposits, deviations from this sequence are found but generally do not involve discrepancies of more than one or two positions in the series**

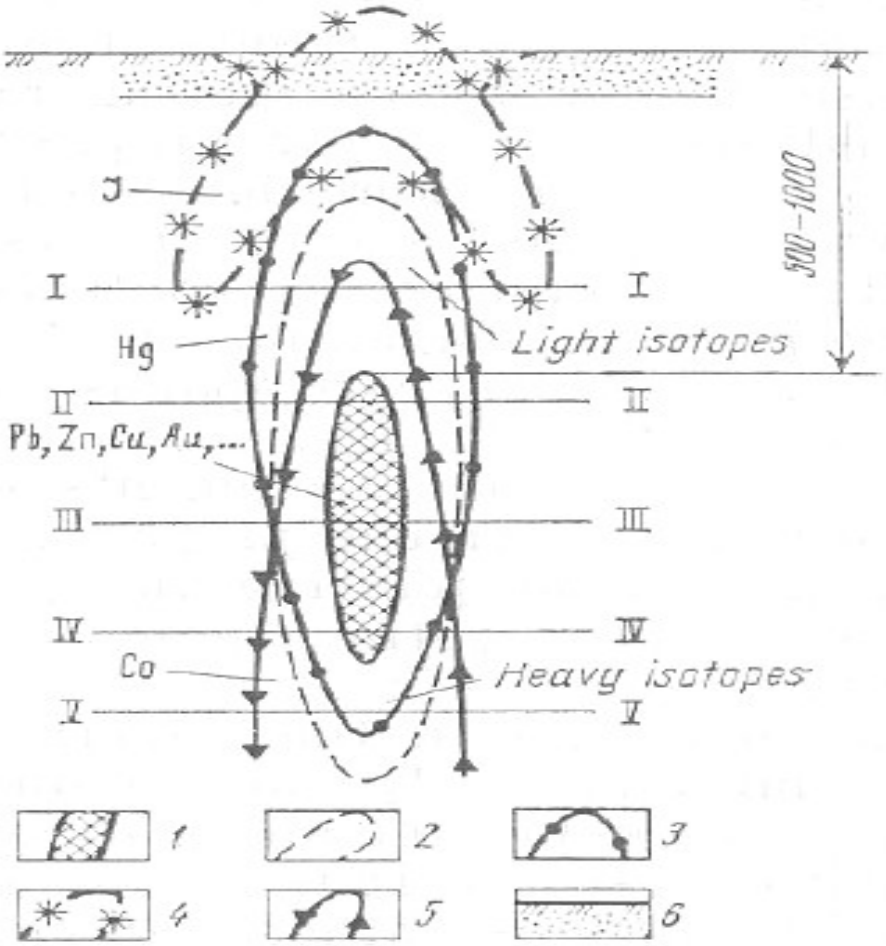



FIG. 57. Model of primary dispersion halos from hydrothermal deposit:

*1* — orebody; primary halos; *2* — Pb; *3* — Hg; *4* — J; *5* — Co; *6* — modern sediments. Roman numerals stand for sequence numbers of horizons

**Enclosing a steeply dipping body of polymetallic ores, the prinicple ore elements (Pb, Zn, Cu, Au) give rise to primary halo that roughly matches ore body shape**

**Lower temperature path elements (Ag, As, Hg) form primary halos shifted along the rise of the ore body**

**Halos from readily volatile elements (Cl, Br, I) are formed in top lying over the ore body**

**The halos from elements of higher temperatures association (W, Mo, Co) are shifted in the direction of dip (downward) from the centre of the ore body**

**From the above, the ore element is lead, low temperature pathfinder element is mercury, high temperature element is cobalt and readily volatile elements is iodine**

# Metallogenic Epochs

**Metallogenetic epochs are specific periods characterized by formation of large number of mineral deposits within 10-20 million years or much less**

**In India, the important metallogenentic epochs are**

1. **Precambrian**
2. **Late Palaeozoic**
3. **Late Mesozoic to Early Tertiary**

# Metallogenic Epochs ……

## Precambrian Epochs

The Precambrian epochs is the most important world over because of great length of time and presence of large and varied mineral deposits

The huge sequence of Precambrian metasediments and associated granitoids, gneisses, etc. are supposed to have a different metallogenic history

The endogenic deposits have been broadly correlated to ultrabasic, basic, acid-intermediate and post-orogenic acidic phases of magmatism.

The exogenic deposits like iron and manganese are related to sedimentary, metamorphic and other processes

# Metallogenic Epochs ……

The iron ore deposits of Precambrian epoch in southern singhbhum (Bihar),

Keonjhar, Mayurbhanj and Sundargarh (Orissa),

Baster and Durg (Madhya Pradesh), Chanda and Ratnagir (Maharashtra),

Dharwar, Bellary, Sendur, Shimoga and Chikmagalur (Karnataka) and Goa

The Chromite deposit in

Singhbhum (Bihar), Dhenkanal, Cuttack and Keonjhar (Orissa), Mysore and Hassan (Karnataka)

Bhandara and Ratnagiri (Maharashtra)

The Gold deposits in

Kolar, Hutti and Gadag (Karnataka)

Ramagiri and Anantpur (Andhra Pradesh)

Wynad (Tamil Nadu) and Kondrakocha (Bihar)

# Metallogenic Epochs ……

**Copper deposit in**

**Singhbhum (Bihar), Khetri (Rajasthan), Malanjkhand (Madhya Pradesh)**

**Mailaram, Gani and Agnigundala (Andhra Pradesh), Ingaldalur and Kalvadi (Karnataka)**

**Lead and Zing in Zawar, Deri, etc (Rajasthan) Sargipalli, Kesarour, Karmali (Orissa), Vadodara (Gujarat)**

**Many more examples are available for Precambrian epoch**

# Metallogenic Epochs ……

## Permo-Carboniferous (Late Palaeozoic) Epoch

Towards the upper Carboniferous (Late Palaeozoic), the Hercynian movements introduced a great changes on the surface of the globe and this movement is marked by mountain building and initiation of sedimentary era

In India, the epoch is known by rich coal deposits of Lower Gondwana for example:

Jharia, Bokaro, Karanpura, Giridih, Ramgarh, Auranga, Hutar, Daltonganj, Deoghar and Rajmahal of Bihar

Raniganj, Barjora and Darjeeling of West Bengal

Singrauli, Korba, Chirimiri, Sohagpur, of Madhyapradesh

A large number of hypabyssal basic intrusive-dolerites and basalt and mica-rich ultrabasic traverse these coal fields

Other important mineral deposits of this epoch are fireclay, iron stone and ochure which occur within Gondwana formation

# Metallogenic Epochs and Provinces……

## Late Mesozoic to Early Tertiary Epoch

This epoch is dominated by fissure eruption of basaltic lave flow (Deccan trap) which is cover 50,000 sq km in western and central India with semi-precious stones like rock crystal, amethyst, agate, onyx chalcedony

Rare copper mineralisation is noted in the trap rock

Igneous activities of this epoch marked by granites, granodiorites, basic and ultrabasic rocks of extra Peninsular India (Main Himalaya, Manipur-Meghalaya and Andaman. These are associated with occurrence of fluorite, copper, lead, zinc, chromaite, magnesite, clay asbestos, magnesite and talc.

Nickel and chromaite in Andaman-Nicobar areas

# METALLOGENIC PROVINCES

**The metallogenic province is known by the name of dominant and specific mineral such as Gold province, Copper province, Iron-ore Province, etc.**

**It may comprise the mineralisation of more than one epoch, each superimposed upon the other**

**In India, many examples for metallogenic provinces, a few of them are**

1. **Gold provinces of Karnataka (Hutti-Kolar) – Andhra Pradesh (Anantpur-Godag) – Tamil Nadu (Wynad)**
2. **Copper province of Singhbhum (Bihar)**
3. **Copper province of Khetri-Pur, Banera-Bhinder (Rajasthan)**
4. **Lead-Zinc province of Hesatu-Belbathan (Jharkhand)**
5. **Iron-ore province of Southern Singhbhum-Keonjhar-Sundergarh-Mayurbhanj**
6. **Iron ore province of Drug-Baster-Chanda-Ratnagiri**
7. **Iron ore province of Karnataka-Goa**
8. **Manganese Province if Balaghat-Bhandara-Nagpur**

# GEOLOGICAL THERMOMETERS

**Minerals which yield information regarding the temperatures of their formation and of the enclosing deposits are said to be geologic thermometers**

**They are very useful in understanding the origin of minerals**

- **These thermometers that record fairly accurately the specific temperature condition of formation of deposits**
- **The thermometers that provide an upper or a lower temperature above or below which the deposits do not form**
- **The thermometers that provide a range of temperature within which the deposit form**
- **The presence of two or more precise geological thermometers in a deposit narrows the range of temperature of formation for the deposits**

# GEOLOGICAL THERMOMETERS….

## Methods for preparation of Geologic thermometry

### 1. Direct Measurement

- This includes direct measurement of temperatures of lavas, fumaroles, hotspring, etc. where the formation of minerals take place.
- A maximum temperature of $1250^0$ C has been recorded for basic lavas
- Fumeroles have a maximum temperature of about $700^0$ C
- According to Bowen, earliest minerals of basic rocks, in general form between $870^0$ C – $600^0$C decreasing with increase of silica content – Chromite which is high temperature mineral form within the above temperature
- The surface temperature of Puga hot springs, ladakh is measured up to $85^0$C. Sulphur, Borax and Potash which occur there may formed at or above the temperature $85^0$C.

## Methods for preparation of Geologic thermometry

### 2. Determination of Melting points and Inversion points of Minerals

- The melting points of minerals indicate the maximum temperature at which they can crystallise
- The melting point of galena is known to be 1120$^0$C. The galena of Hesatu-Belbathan belt, Bihar have formed at the temperature below 1120$^0$C
- The presence of other substances generally reduce the melting point of the minerals

**melting point of some minerals**

- Olivine - 1890$^0$C
- Anorthite - 1550$^0$C
- Antimony - 630$^0$C
- Stibnite - 546$^0$C
- Bismuth - 271$^0$C
- Sulphur - 119$^0$C

**Inversion point of some minerals**

- Tridymite invert to Cristobalite - 1470$^0$C
- Sphalerite to Wurzite - 1020$^0$C
- Kyanite to Mullite - 1000$^0$C
- High Quartz (Beta) to Tridymite - 870$^0$C
- Low Quartz (Alba) to High Quartz - 573$^0$C

## Methods for preparation of Geologic thermometry

### 3. Study of Dissociation, (ii) Exsolution, (iii) Recrystallisation and (iv) Liquid inclusion in minerals

**Dissociation**

- Minerals that dissociate water content or other volatile constituents or any other mineral at certain temperatures may form good geological thermometers
- For example: Zeolite, when heated, lose water content and thus form geological thermometer indicate low temperatures of their formations

  - Tremolite yields diopside at $900^0C$
  - Calcite disscoiates at $900^0C$
  - Pyrite into Pyrrhotite and sulphur vapour at $685^0C$

## Methods for preparation of Geologic thermometry

### 3. Study of Dissociation, (ii) Exsolution, (iii) Recrystallisation and (iv) Liquid inclusion in minerals

**Exsolution**

- Exsolution is separation of one mineral from another at particular temperatures
  - Magnetite to ilmentite at $700^0C$
  - Chalcopyrite to Pyrrhotite at $600^0C$
  - Stannite to Chalcopyrite at $500^0C$
  - Bornite – Tetrahedrite at $275^0C$

**Recrystallisation**

- This method is adopted principally for native minerals
  - Copper - $450^0C$
  - Gold - $360^0C$
  - Silver - $200^0C$

## Methods for preparation of Geologic thermometry

### 3. Study of Dissociation, (ii) Exsolution, (iii) Recrystallisation and (iv) Liquid inclusion in minerals

**Liquid Inclusion**

- It is possible to find out the temperature of formation of the crystals approximately by noting the amount of contraction of the liquid inclusion which filled completely the cavities initially
- To determine the temperature of formation by this method the mineral may be heated till the cavity is completely filled by the inclusion and the temperature at this point may be read
- The temperature of certain sphalerite was found to be 115 to 135$^{0}$C

## Methods for preparation of Geologic thermometry

### 4. Changes in the Physical Properties of some minerals

- Some minerals undergo distinct changes in their physical properties at certain temperatures
  - Limestone – Pigment expelled - $605^0$C
  - Mica - Pleochroic haloes destroyed - $480^0$C
  - Smoky quartz – Colour disappears - $300^0$C
  - Amethyst – Loses colour - $240\text{-}260^0$C
  - Fluorite - Loses colour - Around $175^0$C

### 5. Associated Minerals

- The associated low, intermediate and high temperature minerals give information about their temperature of formation

| High | Intermediate | Low Temperature |
|---|---|---|
| Magnetite | Chalcopyrite | Marcasite |
| Pyrrhotite | Arsenopyrite | Adularia |
| Cassiterite | Galena | Chalcedony |
| Garnet | Sphalerite | Rhodochrosite |
| Pyroxene | Tetrahedrite | Siderite |

| Element | Wt % Oxide | Atom % |
|---|---|---|
| O | | 60.8 |
| Si | 59.3 | 21.2 |
| Al | 15.3 | 6.4 |
| Fe | 7.5 | 2.2 |
| Ca | 6.9 | 2.6 |
| Mg | 4.5 | 2.4 |
| Na | 2.8 | 1.9 |

# Abundance of the elements in the Earth's crust

**Major elements**: usually greater than 1%

$SiO_2$ $Al_2O_3$ FeO* MgO CaO $Na_2O$ $K_2O$ $H_2O$

**Minor elements**: usually 0.1 - 1%

$TiO_2$ MnO $P_2O_5$ $CO_2$

**Trace elements**: usually < 0.1%

everything else

# A typical rock analysis

| Wt. % Oxides to Atom % Conversion | | | | |
|---|---|---|---|---|
| Oxide | Wt. % | Mol Wt. | Atom prop | Atom % |
| $SiO_2$ | 49.20 | 60.09 | 0.82 | 12.25 |
| $TiO_2$ | 1.84 | 95.90 | 0.02 | 0.29 |
| $Al_2O_3$ | 15.74 | 101.96 | 0.31 | 4.62 |
| $Fe_2O_3$ | 3.79 | 159.70 | 0.05 | 0.71 |
| FeO | 7.13 | 71.85 | 0.10 | 1.48 |
| MnO | 0.20 | 70.94 | 0.00 | 0.04 |
| MgO | 6.73 | 40.31 | 0.17 | 2.50 |
| CaO | 9.47 | 56.08 | 0.17 | 2.53 |
| $Na_2O$ | 2.91 | 61.98 | 0.09 | 1.40 |
| $K_2O$ | 1.10 | 94.20 | 0.02 | 0.35 |
| $H_2O^+$ | 0.95 | 18.02 | 0.11 | 1.58 |
| (O) | | | 4.83 | 72.26 |
| Total | 99.06 | | 6.69 | 100.00 |

Must multiply by # of cations in oxide ↑

Table 8-3. Chemical analyses of some representative igneous rocks

| | Peridotite | Basalt | Andesite | Rhyolite | Phonolite |
|---|---|---|---|---|---|
| $SiO_2$ | 42.26 | 49.20 | 57.94 | 72.82 | 56.19 |
| $TiO_2$ | 0.63 | 1.84 | 0.87 | 0.28 | 0.62 |
| $Al_2O_3$ | 4.23 | 15.74 | 17.02 | 13.27 | 19.04 |
| $Fe_2O_3$ | 3.61 | 3.79 | 3.27 | 1.48 | 2.79 |
| FeO | 6.58 | 7.13 | 4.04 | 1.11 | 2.03 |
| MnO | 0.41 | 0.20 | 0.14 | 0.06 | 0.17 |
| MgO | 31.24 | 6.73 | 3.33 | 0.39 | 1.07 |
| CaO | 5.05 | 9.47 | 6.79 | 1.14 | 2.72 |
| $Na_2O$ | 0.49 | 2.91 | 3.48 | 3.55 | 7.79 |
| $K_2O$ | 0.34 | 1.10 | 1.62 | 4.30 | 5.24 |
| $H_2O+$ | 3.91 | 0.95 | 0.83 | 1.10 | 1.57 |
| Total | 98.75 | 99.06 | 99.3 | 99.50 | 99.23 |

## GLOBAL METALLOGENY (in Relation to Crustal Evolution)

**The continents are widely believed to have developed by accretion**

**Each continent has developed from a volcanic nucleus or nuclei, being joined and added to by peripheral volcanic nuclei.**

**The process is aided by the accumulation of volcanic matter (pyroclastic material) and products of erosion.**

**The pattern is complicated by later fractures and relative movement, perhaps drift, of various crustal segments. This evolutionary pattern seems to form a plausible framework for the succession of geologic environments and evolution of ore types.**

The process of crustal evolution is considered in six successive stages.

# STAGE I: THE EARLY VOLCANIC STAGE

**The beginning of crustal evolution is marked by the formation of broad swells on the basaltic ocean floor.**

**These represent the early stages in the development of volcanic islands.**

**Development of these swells leads to block faulting, extrusion of lavas, and their protrusion above the sea level to form volcanic islands (Eg Solomon Is in SW Pacific)**

***MINERAL DEPOSITS:***

**Native copper and associated sulfides as orthomagmatic disseminations and vesicular fillings Eg Solomon Islands.**

**Nickel and associated sulfides in volcanic sills Eg Kambalda, W Australia, Manitoba. Precious metals viz. tellurides Eg Fiji.**

**Minor chemical sedimentation viz. manganese and iron with jasper.**

## STAGE II: EARLY ALPINE TYPE ULTRAMAFIC STAGE

**Vulcanism continues, but changes to basaltic andesite, gradually progressing to andesites, dacites and rhyolites.**

**Pyroclastic activity becomes prominant with the onset of the andesitic stage and increases with the increase in the felsic nature of vulcanism.**

**The older swells are undergoing extensive erosion and much sedimentation. The sediments become folded, faulted and deformed due to near vertical block faulting and gravity collapse.**

### *MINERAL DEPOSITS:*

**Alpine type chromite deposits in intrusives Eg Paleozoic to Tertiary "Serpentine Belts" everywhere.**

**Nickel sulfide concentrations and Nickel also occurs as Ni-rich olivine which may be concentrated to ore by later weathering.**

## STAGE III: DEVELOPING EUGEOSYNCLINAL STAGE

The volcanic islands are by now well established and are enlarged by bodily uplift, volcanic accretion and sedimentation. Volcanic products are becoming more felsic and pyroclastic material is becoming prominent. Earliest plutonic rocks of granitoid texture and dioritic- granodioritic composition appear (in pipe or stock form). These are of shallow subvolcanic nature. These may be products of magmatic differentiation or transformation of the deeply buried pyroclastic rocks.

### *MINERAL DEPOSITS:*

Banded Iron Formations developed as volcanic chemical sediments as a result of sea-floor exhalative activity. Deposition of these took place in troughs (eugeosynclines) in inter-island regions of arcs. Considerable jasper and some manganese Eg Guyana.

Stratiforn Sulfide Deposits of marine and marine-volcanic affiliation. All these are essentially sea floor volcanic accumulations.

A few of these are associated with basaltic and more mafic lavas Eg Cyprus and Japan, whereas a vast majority are associated with andesitic and dacitic rocks. Eg Base metals of Ontario, Mount Isa and McArthur River (Precambrian); Bathurst, New Brunswick and E. Australia (Paleozoic) and Japan (Tertiary).

Some Banded Iron Formations and minor manganese concentrations and barite are associated with the Stratiform Sulfide Deposits. Most of these deposits are formed near the continental margins and biological activity (2500 y ago) is always indicated.

## STAGE IV: ADVANCED EUGEOSYNCLINAL & MIOGEOSYNCLINAL STAGE

**The oldest swells have become quite large (Java & Sumatra) with smaller intervening swells beginning to coalesce (Aleutian-Malaysian).**

**There is a mixing of volcanic material with products of continental erosion around volcanic festoons bordering continents. There is, therefore, a hybrid sedimentation on the continental side of the arc (the miogeosyncline) while volcanic sedimentation progresses in the outward seaward trough (the eugeosyncline). Vulcanism at this stage becomes more felsic.**

### *MINERAL DEPOSITS*

**Stratiform or non-stratiform marine volcanic sulfide ores.**

**Banded Iron Formations in the eugeosynclines (for some reason major iron formations are not associated with basemetal sulfide deposits).**

**Volcanic basemetals are contributed to the reef and off-reef environments on both sides of the arc (particularly on the miogeosynclinal side). These are eventually concentrated by sedimentary, diagenetic and later processes to form Limestone-Lead-Zinc Deposits.**

**Some manganese deposits (Usinsk Type) also develop in the eugeosynclines and miogeosynclines.**

# STAGE V: EARLY CONTINENTAL AND INTRUSIVE STAGE

The volcanic islands are by now welded to each other and also to the continental margins. Intense fault movement, compressional folding, more felsic plutonic intrusions, waning of vulcanism and rapid erosion are characteristic of this stage of crustal evolution. Plutonic rocks are granitic and pegmatitic in composition.

## *MINERAL DEPOSITS:*

Cassiterite deposits as disseminations in granites, contact metamorphic deposits and pegmatitic deposits.
Quartz-cassiterite veins. Quartz-wolframite veins. Quartz-scheelite veins.
Quartz-gold veins. Stibnite and stibnite-scheelite-gold veins.
Basemetal sulfide veins with arsenopyrite and increasing proportions of Pb & Zn as compared to Cu. Plutonic type anorthositic iron-titanium oxides.
In the more mafic parts of these intrusions chromite is segregated. Eg Bushveld Complex.
Sometimes ilmenite, magnetite and minor Fe-Ti-O. Major nickel-copper sulfides (Eg Sudbury) are also identified with this stage
Chromite deposits formed in ultramafic rocks during the Alpine Type Ultramafic Stage (II) are well serpentinized by this time and move along large fault systems (along which they formed) and take up new lithological and structural positions in the evolving crust.

## STAGE VI: SHELF AND SHIELD STAGE

**Continuing folding, faulting and varying degrees of metamorphism leads to the formation of a "Continental Shield". This stage is marked by outpouring of flood basalts and stabilization of the crustal segment.**

**Erosion and peneplanation lead to the development of broad flat areas susceptible to inundation during sea-level rises resulting in extensive deposits of detrital sediments, reefs (carbonate), evaporites and chemical sediments.**

**Movement of the shoreline in response to sea-level fluctuations leads to the interfingering of shallow water marine and fluviatile sediments, particularly in the lower reaches of braided streams, deltas and outwash fans.**

**Mineral deposits forming at this stage include a variety of igneous and sedimentary ores, and deposits formed during the earlier stages undergo substantial metamorphism.**

## *MINERAL DEPOSITS:*

**There are few mineral deposits associated with flood basalts. Exceptions are the copper bearing lavas of the eweenaw Peninsula, Lake Superior.**

**Limestone-lead-zinc deposits often associated with oil bearing strata and evaporites, Eg Pine Point, Canada.**

**Non-volcanic sedimentary manganese deposits (orthoquartzite-glauconite-clay association), Eg Nikopol, USSR, and Morocco.**

**Ironstones of the Clinton, Lorraine and English type associated with near-shore, estuarine or lagoonal sedimentation.**

**"Sandstone Type" Cu-U-V ores formed in coarse sediments of outwash fans, near-shore braided streams and deltas, Eg Colorado.**

**Gold-uranium deposits of Witwatersrand-Bhind River- Jacobina Type in coarse conglomerates and grits of braided stream channels.**

**Basemetal sulfide deposits of non-volcanic association occurring with evaporites, Eg Kupferschiefer Marl Slate of Europe and England and the Copperbelt of Zambia.**

# MAJOR ORE TYPES OF INDIA AND THEIR TECTONIC SETTING

| | TYPES OF ORE DEPOSITS | TECTONIC SETTING | LOCALITY | GEOLOGICAL AGE |
|---|---|---|---|---|
| 1. | RELATED TO BASIC/ULTRABASIC IGNEOUS INTRUSIVES. | | | |
| 1.1 | Stratiform deposits in layered complexes | Cratons | Kondepalle(?)<br>Sitampundi(?)<br>Hassan | Early Proterozoic<br>Early Proterozoin<br>Archaean |
| 2. | MASSIVE SULFIDE DEPOSITS IN VOLCANIC ASSOCIATION | | | |
| 2.1 | Cupreferous deposits associated with mafic volcanics | Rift-ridges/island arcs/craton-margin dislocations. | Kalyadi (S. India)<br>Ingaldahl<br>Singhbhum | Archaean<br>Archaean-E. Proterozoic<br>Early-Late Proterozoic |
| 3. | ORES IN SEDIMENTS | | | |
| 3.1 | Sediment hosted sulfide deposits | Ensialic Rift Basins | Khetri | Mid-Late Proterozoic |
| 3.2 | Lead-zinc ores in clastic sediments | Ensialic Rift Basins/Epicontinental Basins | Agucha<br>Rajpura-Dariba | Archaean<br>Mid-Late Proterozoic |
| 3.3 | Lead-zinc ores in carbonate rocks (Bulk Mississippi Valley type) | Ensialic Rift Basins/Epicontinental Basins | Zawar(?) | Early Proterozoic |
| 3.4<br>3.4.1 | Iron Ores<br>Banded Iron Formations | Greenstone Belts/Epicontinental Basins | Bababudan-Sandur<br>Bihar Orissa(?) | Archaean-E. Proterozoic<br>Late Archaean |
| 3.5 | Manganese Ores | Ensialic Basins/epicontinental seas/eugeosynclines | Bihar-Orissa<br>Madhya Pradesh-Maharashtra | Late Archaean<br>Mid- Late Proterozoic |

| | | | | |
|---|---|---|---|---|
| 4. | ORE DEPOSITS ASSOCIATED WITH ACID-INTERMEDIATE PLUTONIC/HYPABYSSAL ROCKS | | | |
| 4.1 | Porphyry-type copper deposits | Orogenic belts/subduction zones | Malanjkhand | Early-Middle Proterozoic |
| 4.2 | Tin-tungsten deposits | Orogenic belts with ensialic magmatism | Chhendapathar(?) | Late Proterozoic |
| 5. | VEIN DEPOSITS IN METAMORPHOSED ROCKS | | | |
| 5.1 | Gold-quartz veins | Greenstone belts and<br>Phanerozoic orogens | Kolar<br>Hutti | Archaean<br>Archaean |
| 5.2 | Uranium veins in shear zones | Regional shear zones | Singhbhum | Middle-Late Proterozoic |
| 6. | LATERITIC DEPOSITS | | | |
| 6.1 | Bauxite deposits | Continental platforms | Bihar-Madhya Pradesh | Phanerozoic |
| 6.2 | Lateritic Ni-deposits | Non-specific | Sukinda | Phanerozoic |