Indira Gandhi National Open University
School of Sciences

BGYCT - 133 CRYSTALLOGRAPHY, MINERALOGY AND ECONOMIC GEOLOGY

Block

4

ECONOMIC GEOLOGY

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BGYCT-133: CRYSTALLOGRAPHY, MINERALOGY AND ECONOMIC GEOLOGY

BLOCK 4: ECONOMIC GEOLOGY

Minerals of economic importance play a vital role in all walks of human life as well as stages of advancement of a civilisation. The nomenclature used to describe pre-historic periods such as Stone Age, Bronze Age, Copper Age or Iron Age is based on prolific usage of Earth materials during that period. Kautilya in the 4th century B.C. in his well-known treatise 'Arthashastra', stated that the wealth obtained from mining operations would be utilised in functioning of seven departments controlling the various branches of the mining and mineral industry. Kautilya, had also suggested the means of identification of various ores of copper, lead, tin, iron, silver, gold and possibly uranium. Economic Geology is one of the subdisciplines of geology devoted to scientific study of the Earth's resources involving their distribution, economic considerations concerning their exploitation and also the assessment of the available reserves.

This block comprises five units, wherein you will be introduced to the basic concepts of ore and ore deposits, processes of ore formation, metallic minerals, non-metallic minerals deposits and coal and petroleum.

Unit 11 Ore and Ore Deposits is devoted to the introduction of fundamental concepts related to ore and ore deposits, processes of ore formation, morphology and nature of ore deposits, metallic and non-metallic minerals, strategic, critical and essential mineral deposits.

In **Unit 12 Processes of Ore Formation,** you will learn about the classification of ore forming processes. Endogenous ore forming processes such as magmatic concentration, sublimation, pegmatite / pneumatolytic, hydrothermal, contact metamorphism and metasomatism will be discussed. You will also learn about the exogenous processes of ore formation such as sedimentation, residual and mechanical concentration, oxidation and supergene enrichment and evaporation.

In **Unit 13 Metallic Minerals,** you will learn about the chief ores of common metals, such as ferrous metals (iron and manganese), base metals (copper, lead and zinc), precious metals (gold and silver), light metal (aluminium) and radioactive metals such as uranium and thorium. Their processes of formation, distribution in India and uses will be discussed.

Unit 14 Non-Metallic Minerals introduces you to the industrial minerals such as mica, gypsum and magnesite. It also discusses about the building and construction materials like granite, marble and limestone. This unit provides an elaborate discussion on minerals used in refractory, ceramic and glass manufacturing industries, fertiliser, chemical, paint and pigments and abrasive industries. You will also read about gemstones.

In **Unit 15 Coal and Petroleum,** you will be introduced to coal and petroleum. You will read about the origin, varieties, rank and grades of coal, mode of occurrence and formation of coal and petroleum deposits. Indian occurrences of coal and petroleum have also been discussed.

Expected Learning Outcomes

After studying this block, you should be able to:

- discuss the basic concepts of ore and ore deposits, morphology and nature of ore deposits and processes of their formation;

- recognise the types of metallic, non-metallic, strategic, critical and essential mineral deposits;
- identify and discuss various endogenic and exogenic ore forming processes;
- describe chief types of ores of iron and manganese, copper, lead and zinc, gold, aluminium and radioactive minerals, their processes of formation and distribution in India and uses;
- describe industrial minerals, building and construction materials and minerals used in refractory, ceramic and glass manufacturing industries, fertiliser, chemical, paints and pigments and abrasive industries; and
- discuss origin, mode of occurrence, formation of coal and petroleum and their Indian occurrences.

We hope that after studying this block, you will acquire knowledge about the basic concepts of ore deposits, processes of ore formation, nature and morphology of ore bodies, metallic and non-metallic minerals and coal and petroleum.

Wishing you success in this endeavour!

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UNIT 11

ORE AND ORE DEPOSITS

Structure

11.1 INTRODUCTION

Economic geology had its inception with utilisation of metals and mineral products from prehistoric time. However, long time period must have passed, before the early crude knowledge which was undoubtedly utilitarian gave birth to an intellectual thinking by the Greek philosophers. The first Earth materials used by primitive man were non-metallic minerals like flint, chert, quartz, and certain hard and soft stones such as soapstone or limestone. The early man used them in weapons, implements, utensils and for carving. The ancient Indians appear to have practised the process of distillation and calcination of minerals and their ores. Apart from this, clay was widely and extensively used for manufacturing pottery and bricks.

Among the metals gold appears to have attracted the attention of early man even before copper. There is a very ancient shaft about 640 feet deep in the Hutti mine area of Raichur District in Karnataka state which appears to have been operating even during the reign of Emperor Asoka (240 BC). There are frequent mention of gold and silver in the Vedic mantras written probably 2000 BC. The evidences obtained from Mohenjodaro and Harappa civilisations also indicate the abundant usage of metals like gold, silver, copper, lead and zinc, iron and tin.

We have learnt in Unit 4 Minerals that mineralogy (or mineral science) is the study of naturally occurring, inorganic solid substances called minerals. Now in this unit, we will discuss various aspects pertaining to economic geology like concept of ore and ore deposits, processes of ore formation, metallic and non-metallic minerals and origin, occurrence and distribution of coal and petroleum.

Expected Learning Outcomes

After reading this unit you should be able to:

- describe the scope of economic geology and its relationship with other branches of geology;
- define ore and terminologies related to ore deposits;
- discuss the concept of ore and ore deposits:
- list processes of ore formation;
- discuss the morphology and nature of ore deposits; and
- describe metallic, non-metallic, strategic, critical and essential mineral deposits.

11.2 SCOPE OF ECONOMIC GEOLOGY

We have read the definition of economic geology in previous section now let us discuss the scope of economic geology.

Economic Geology is the branch of geology that deals with the scientific study and extraction of Earth's resources like minerals, ores, rocks, ground water etc. It leads us in the search of new mineral deposits and in their detailed investigations (Pohl, 2011). 'The discipline of 'economic geology' covers all aspects pertaining to the description and understanding of mineral resources. It is also the discipline that underpins the training of professional Earth scientists working in the minerals and related industries of the world' (Robb, 2015). Economic geology is one of the core components of Earth science undergraduate and postgraduate curriculum.

Economic geology deals with the materials of the mineral kingdom that man derives from the earth for his necessities of life and comfort. This search and discovery has given rise to settlement of new lands. The ownership of mineral deposits has resulted in commercial or political supremacy or has caused strife and war. We are witnessing in present scenario that with the accelerating growth of world's population and improvement of living standards, the demands for all types of minerals and metals have increased, which in future will continue to grow. Therefore the search for mineral

deposits is becoming more complex with the escalating urbanisation and industrialisation. Thus man is continuously in the process to devise new geologic, geochemical and geophysical exploration techniques and ideas to supplement the existing ones, in order to obtain sufficient supplies for the future.

The recovery, recycling and mining techniques are being improved so that large bodies of near-surface economic minerals in future can be explored with due regard for ecological and environmental constraints. Hence a successful economic geologist must develop 'exploration thinking' requiring originality in imagination with a degree of optimism. The economic geologist should also possess a thorough knowledge of structural geology, stratigraphy, petrology and mineralogy (Fig.11.1). Since the tools like geochemistry and geophysics are becoming increasingly useful in the search for buried deposits thus the economic geologists should also be familiar with their fundamental techniques. Economic geologist is also required to be able to interpret the field and laboratory significance of observable relationship of minerals deposits using geologic, geochemical, geophysical, and mathematical and computer skills. We can say this field of study of economic geology is concerned with the distribution of mineral deposits, the economic considerations involved in their recovery, and the assessment of available reserves. According to Lindgren (1933) 'the broad domain economic geology stands on the fundamental sciences of chemistry and physics. It is related to theoretical geology, palaeontology, mineralogy, and petrography on one side; on another side to mining, metallurgy, and many other technological arts; on still another side to economics and finance'.

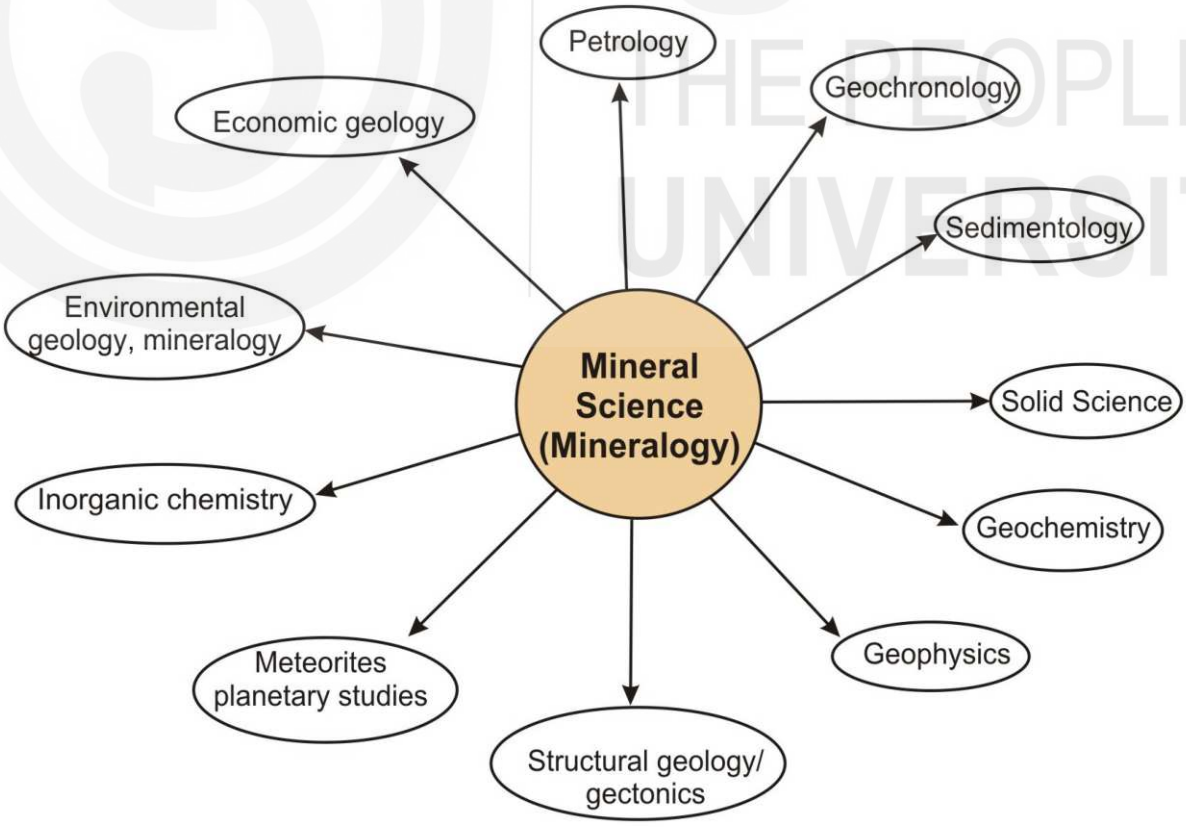


Fig. 11.1: Relationship of Mineralogy (economic geology) with mineral science and other branches of Earth science. (Modified after, Shrivastava, 2009)

11.3 CONCEPT OF ORE AND ORE DEPOSITS

We have learnt about the scope of economic geology in earlier section. Now in this section we will learn the definitions about the basic terminology, and concepts of ore and ore deposit.

11.3.1 Basic Terminology

Let us learn some basic definitions related to economic geology.

Ore: The word ore has been derived from the Middle English, *oor*, because of its similarity to earlier names for copper ore and brass. **Ore** is defined as a naturally occurring mineral or aggregate of minerals from which metal/metals could be extracted with profit. It usually occurs with useless gangue mineral or mineral aggregates, substance or unwanted substance. In simplified words, we can define ore as an aggregation of one or more ore minerals and gangue from which one or more metals are extracted profitably. After their mining the ores are further processed to extract the elements of interest from the waste rock and from the ore minerals. Metal ores commonly concentrated in the Earth's crust are generally sulphides, oxides, silicates or native metals (like gold). The term ore is generally confined to the sources of metallic minerals. The minerals having appreciable concentration of metallic elements are called as **ore minerals**.

Let us study an example of **why a mineral is called as ore**?

Chalcopyrite is a mineral (it is naturally occurring and has a fixed chemical composition- $CuFeS_2$), but also an ore of copper; when you find huge quantities of mineral chalcopyrite confined in a place it constitutes an economic mineral or ore deposit of copper. Thus the ore minerals are different from common rocks and minerals.

Ore deposits or mineral deposits are natural concentrations of useful minerals or rocks, which can be economically exploited (Fig. 11.2 and 11.3). Concentrations that are too small or too low-grade for mining are called occurrence or mineralisation (Pohl, 2011). The definition of ore deposits includes ores of metals and non metals, industrial minerals, gemstones, rocks used as aggregate for building stone and coal and oil shale.

Let us discuss an example of ore deposit. Copper mineralisation in Malanjkhand mine located in the Balaghat District of Madhya Pradesh state (Fig. 11.2), is found within tonalite-granodiorite plutonic rocks. The bulk of the mineralisation occurs in sheeted quartz-sulfide veins and potassium-silicate alteration zones. This entire assemblage of rock types together with copper mineralisation constitutes an ore deposit.

Ore bodies: The ore deposit consists of the rock bodies or ore bodies (Fig. 11.3) enclosing one or more ore minerals along with those natural materials which are not ore. Not all the ore within the ore body will be extracted. Ore bodies are divided into reserves and resources.

Fig. 11.2: Panoramic view of Malanjkhand copper deposits.

Gangue: It is the commercially worthless material that surrounds or is closely mixed with wanted mineral in an ore deposits. Let us read about the difference between ore and gangue. Minerals with high percentage of metal, that can be profitably extracted is known as ore. The term gangue refers to the impurities like sand, soil that are removed from the ores.

Reserves are ore that are economically feasible to mine and for which there are no legal or engineering impediments to mining.

Resources are ores that may potentially be extracted at sometimes in the future.

Fig. 11.3: Malanjkhand copper deposits showing ore bodies marked by black arrows.

Industrial minerals: They have been defined as any rock, mineral or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels and gemstones (Noetstaller, 1988). The non-metallic minerals are considered as industrial minerals rather than ores. Thus, galena (PbS) is an ore mineral, while halite (NaCl) and phosphorite or rock phosphate ($Ca_5FO_{12}P_3$) (Fig. 11.4) are industrial minerals. Many other minerals are mined for industrial uses, namely cement, building stone, abrasives, fertilisers, fillers, fluxes, ceramics, glasses, etc. They are classed as industrial minerals. Although practically all industrial minerals contain metallic elements and they are often confused with non-metallic. Many metallic ores, such as bauxite, ilmenite, chromite and manganese minerals are also considered important raw materials for industrial minerals.

Fig. 11.4: Phosphorite/rock phosphate deposit at Jhamarkotra in Rajasthan. (Photo credit: Ganga Singh Bhartiya)

Apart from metals and non-metals there is another category of economically important natural energy resources commonly known as **fossil fuel** like coal, petroleum, natural gas and the **radioactive minerals**. You have read in Unit 4 that as per the definition of a mineral, coal, petroleum and natural gas are not considered as minerals however they form significant economic deposits.

Host Rock: It is the rock which surrounds or encloses ore deposits and like gangue it has no commercial value.

Tenor: It is the actual metal content present in an ore. Tenor in case of non-metallic minerals refers to the percentage of metal content in an ore mined, whereas in case of metallic minerals, it signifies metal content in an ore mined. For example, in case of asbestos the tenor is 6%. It means that the occurrence of asbestos fiber in the ore is 6%. While metallic deposits, such as copper ore, it is referred to as 2%, it means that the ore contains 2% copper metal. The tenor may reach up to 100% in the case of native deposits. It may vary from deposits to deposit. The lower limit of tenor is dependent upon the various techno-economic factors such as location, size, price, and

advancement of mining and extractive technology. It also depends upon the presence of other recoverable substances. Tenor is described as economic indicator because it has great economic significance, particularly to the life of a mine or deposit.

Ore Grade: The term ore grade is used in the commercial classification of ores which takes into account the chemical and physical properties of an ore. It is usually expressed as percentage or parts per million (ppm) for metal contents, e.g. Cr_2O_3 in chromite ore, WO_3 in tungsten ore and P_2O_5 in apatite and rock phosphate. While penny weight, troy ounce, gram per unit weight is used for precious minerals. Ore grade is also an expression of the quality of the deposit. The strength of the material and colour are also important and taken into account for grading. Carbon concentration, ash content, volatile matter, calorific value, moisture and caking quality all together determine a grade in case of coal. In some cases, impurities also determine the grade of an ore, e.g. presence of sulphur and phosphorous in iron and manganese ores and coal. Shape and size of ore deposits affect the workable grade. Large, low grade deposits which occur at the surface can be exploited by cheap open pit methods, whilst thick tabular vein deposits require more expensive underground extraction methods.

Specification: It is another important term which is related with the grade. It focuses on the tolerance limits of all constituents present in it and depends upon:

- Technique of manufacturing process adopted by individual units; and
- Grade of other raw material required to be used as whole or to obtain the end product.

Beneficiation: It refers to improving the quality of an ore mineral before feeding smelting or other operations. Different physical or chemical methods are used to separate the gangue or undesired minerals from the ore minerals.

Ore magma: This term is used for the abnormally rich magma that crystallises out into an ore most often in case of sulphide or oxide ore minerals.

Ore guides: The final aim of the geologist is to detect subsurface ore bodies. The exploration for ore bodies is often done with the help of ore guides. Thus ore guides are structural or other features and conditions which serve as clues to the location of ore body. The most practical and definite type of guides are those that are capable of representation on maps, sections or models. The ore guides include geological, geochemical, botanical and biogeochemical observations or even biotic activity that provides clue about sub-surface mineralisation.

Ore genesis: The ore deposits are formed by variety of geological processes and the process of their formation is called ore genesis.

Ore shoot: This term is commonly used in mining operations. These are relatively rich portions of mineralised body.

Ore microscopy: Most of the metallic ores are opaque. Therefore study of ore requires a specially designed microscope called as ore microscope, where polished ore sections or slabs are studied under the microscope in a reflected light.

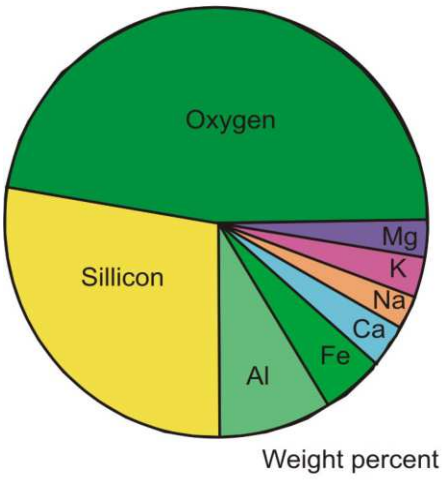
Gossan: They are signboards that point to what lies beneath the surface. The word '*gossan*' is a Cornish word and is used to designate the oxidised outcropping comprising cellular mass of limonite. The outcropping of cellular mass of limonite or capping is the leached upper part of a rock body that contains disseminated sulfide minerals (Fig. 11.5). They are quite interesting and draw attention as to what they may

mask. In other words, gossans are most significant indicators of the previous existence of sulphide ore, including porphyry systems and other ore forming environment.

Fig. 11.5: Capping of the upper part of ore body shows oxidised outcropping of limonite. (Photo credit: Ganga Singh Bhartiya)

11.3.2 Clarke and Clarke of Concentration

Let us consider a thorough mixture of all varieties of rocks (igneous, sedimentary and metamorphic) constituting around 30 km of crustal rocks. The data shows that all the elements are present in the crust, though not in uniform distribution. The abundance of different elements in such a mixture of rocks is referred to **average crustal abundance** (Fig. 11.6). In such a hypothetical composition, only eight elements are worth mentioning. In order of abundance, they are O (46.6%), Si (26.72%), Al (8.13%), Fe (5.00%), Mg (2.09%), Ca (3.63%), Na (2.83%) and K (2.59%). Rest of the elements constitutes only around 1% of the average crustal abundance. However, the Earth's crust does not have such an idealised composition.



	Weight percent	Atom percent	Iconic radius (A)	Volume percent
O	46.60	62.55	1.36	~94
Si	26.72	21.22	0.26(4)	
Al	8.13	6.47	0.39(4)	
Fe	5.00	1.92	0.78(6)	
Ca	3.63	1.94	1.00(6)	~6% in total
Na	2.83	2.64	1.02(6)	
K	2.59	1.42	1.51(8)	
Mg	2.09	1.84	0.72(8)	
	98.59	100.00		

Fig 11.6: Eight abundant elements in the Earth's crust (Modified after Mason and Moore, 1982)**. Numbers in square brackets refer to coordination number.** (Modified after Klein, 2008)

Let us discuss the two terms 'Clarke value' and 'Clarke of concentration'. They are important to understand concept of ore in comparison to average crustal abundance. Famous Russian geochemists Fersman and Vernadsy introduces these two important terms in honour of F.W. Clarke, who was Chief Chemist of United States Geological Survey for 41 years (1884-1925). **Clarke value** refers to the average abundance of a particular element in the Earth's crust. Clarke values are synonymous with the crustal abundances. **Clarke of Concentration** is the concentration of an element in a particular rock compared with its average concentration in the Earth's crust, or of an element within a particular mineral. It represents how many times the average crustal abundance of a particular element needs to be enhanced to become an ore mineral. Thus, **ore is always defined in terms of its comparison with the average percentage of an element in the Earth's crust**.

Let us study an example to understand these definitions. Clarke (abundance of that particular metal in Earth's crust) of copper (Cu) is about 55 ppm or 0.006%; in the mineral chalcocite (Cu_2S), Cu concentration is 79.8%. Thus, the Clarke of Concentration within chalcocite mineral is 79.8/0.006, or 13,300. We will look at another example. The average crustal abundance of Mn at 0.1% is termed as Clarke of Mn, but when this is enhanced to 632 times due to various complex natural processes such as in the ore mineral pyrolusite. Thus, the Clarke of Concentration of Mn in pyrolusite (MnO_2) is 632/0.1 or 6320. We should note that Clarke of Concentration values is not same for all the elements and also differ for the same elements found in different ore minerals (Table 11.1).

Table 11.1: Concentrations of some economically important metals in average upper crust (Clarke values), and typical grades and enrichment factor of ores (Clarke of concentration). Compositions are in ppm, except where indicated. (Source: Ridley, 2013)

Metal	Clarke=average concentration in upper crust	Grade in typical ore	Clarke of concentration=enrichment factor of average crust → ore
Al	8%	30%	4
Fe	5%	60%	12
Mn	950	5%	50
Cr	100	5%	500
Cu	55	1%	200
Ni	75	1%	100
Zn	70	10%	1000
Sn	2	1%	5000
Pb	12	10%	10,000
Au	0.004	5%	1200
U	3	0.1%	300

Watch the following videos to know more about the classification and types of ore deposits.

- Introduction to ore deposits
  Link: http://egyankosh.ac.in//handle/123456789/53454

- Classification of ore deposits
  Link: http://egyankosh.ac.in//handle/123456789/53455

11.4 PROCESSES OF FORMATION OF ORE DEPOSITS

After having learnt about concept of ore deposits, we will read about processes of formation of ore deposits. We can categorise the processes of ore formation into endogenous and exogenous processes. **Endogenous processes** result from the dynamics of the Earth's interior that mainly result due to the heat flow of the Earth.

Such type of processes operative in the primary environment are characterised by high pressure, high temperature and low oxygen conditions. **Exogenous processes** take place on the surface of the Earth that is mainly due to the flow of energy from the Sun. Let us list the endogenic and exogenic processes as given below in Table 11.2.

Table 11.2: Endogenic and exogenic processes.

Endogenous processes	**Exogenous processes**
Magmatic concentration / segregation (early and late magmatic)	Sedimentation
Sublimation	Residual and Mechanical concentration
Pegmatite / Pneumatolytic	Oxidation and Supergene enrichment
Hydrothermal	Evaporation
Contact metasomatism and contact metamorphism	Bacteriogenic precipitation
Metamorphism	Syn-sedimentary volcanogenic

We will discuss these processes in detail in Unit 12 Processes of Ore Formation of this course. In the previous sections we have studied about the concept of ore formation. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 1

1. How metallic minerals are different from non-metallic /industrial minerals?
2. How economic geology is related to other disciplines of geology?
3. Define ores. How ore is different from gangue?
4. List endogenic and exogenic processes.

11.5 NATURE AND MORPHOLOGY OF ORE BODIES

Now before we discuss the nature and morphology of ore bodies let us read two terms which are often used by mining geologists, i.e. syngenetic and epigenetic deposits.

Syngenetic deposit is the ore deposit which has formed by the same process and at the same time as the enclosing rock in which it occurs is sometimes part of a stratigraphical succession, such as an iron-rich sedimentary horizon.

Epigenetic deposit is the ore deposit which has formed after the formation of host rock in which they occur, e.g. vein. These ore minerals have been introduced into pre-existing country rock after their formation.

We can study the nature and morphology of ore deposits under two categories in the same way as it is done for igneous rocks. You will study about igneous rocks in Unit 1 of BGYCT-135 course.

- **Discordant ore body** refers to ore body which cuts across the bedding plane or banding.
- **Concordant ore body** refers to ore body which is parallel to the lithological bedding plane or banding.

11.5.1 Discordant Ore Bodies

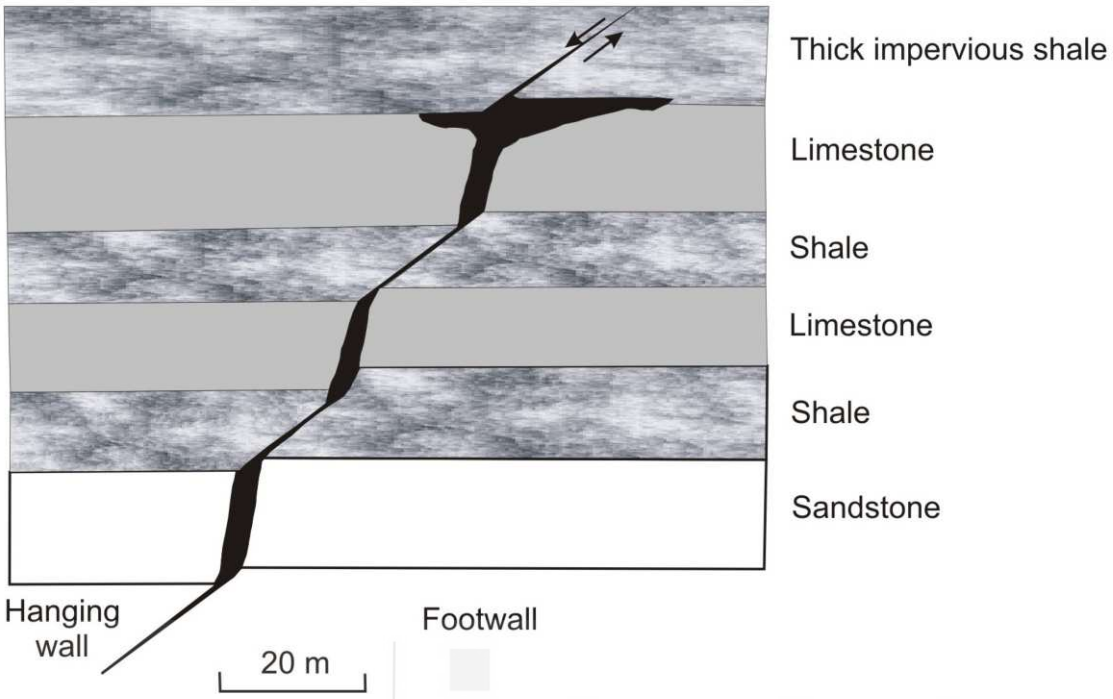
We can further divide the discordant ore bodies on the basis of their shape into:

- Regularly shaped ore bodies
- Irregularly shaped ore bodies

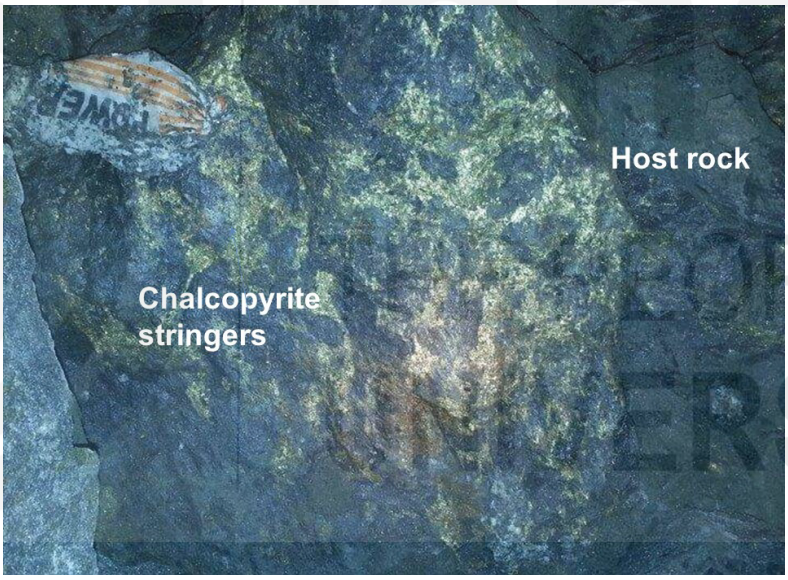
Let us read about them.

A) Regularly Shaped Ore Bodies

i) **Tabular ore bodies**: These bodies are extensive in two dimensions, but have a restricted development in their third dimension. In this we find veins (sometimes called fissure-veins) and lodes. Veins are considered to have resulted mainly from the infilling of pre-existing open spaces. While the formation of lodes involve the extensive replacement of pre-existing host rock. **Veins of ore** are deposited between the layers of rock. Veins are often inclined and frequently pinch and swell out as they follow up or down a stratigraphical sequence (Fig. 11.7a). **Lode** is a deposit of metallic ore that fills or is embedded in the fissure or crack in the rock formation. **Stringer lode** is a deposit of metallic ore which is permeated by many irregular branching and anastomosing stringers and small veinlets (Fig. 11.7b and b) so that the entire mass of ore and the host rock is mined (as it is inseparable from the country rock).



(a)



(b)

(c)

Fig. 11.7: a) Vein occupying a normal fault and exhibiting pinch and swell structure, giving rise to ribbon ore shoots (Source Alexander, 2009)**; b) Outcrop containing chalcopyrite deposits (golden yellow) are in form of stringers at 225m depth, host rock is biotite chlorite schist (bluish grey); and c) Hand specimen of copper ore in for of stringers (marked by red arrow) from Surda mine, Ghatshila. Host rock is quartz.** (Photo credit: Saurabh Sinha)

ii) **Tubular ore bodies**: As the name implies, tubular ore bodies are restricted in two dimensions. They are extensive in the third dimension. When they are vertical or subvertical they are called pipes or chimneys. '*Mantos*' (Spanish word meaning 'blanket') are horizontal or subhorizontal tubular ore bodies. Mantos and pipes may branch and anastomose as shown in Fig. 11.8. They are often found occurring in association with the pipes which frequently act as feeders. Sometimes mantos pass upwards from bed to bed by way of pipe connections. We also find discontinuous pod shaped bodies when mineralisation takes place in some tubular deposits formed by sub-horizontal flow of mineralising fluid.

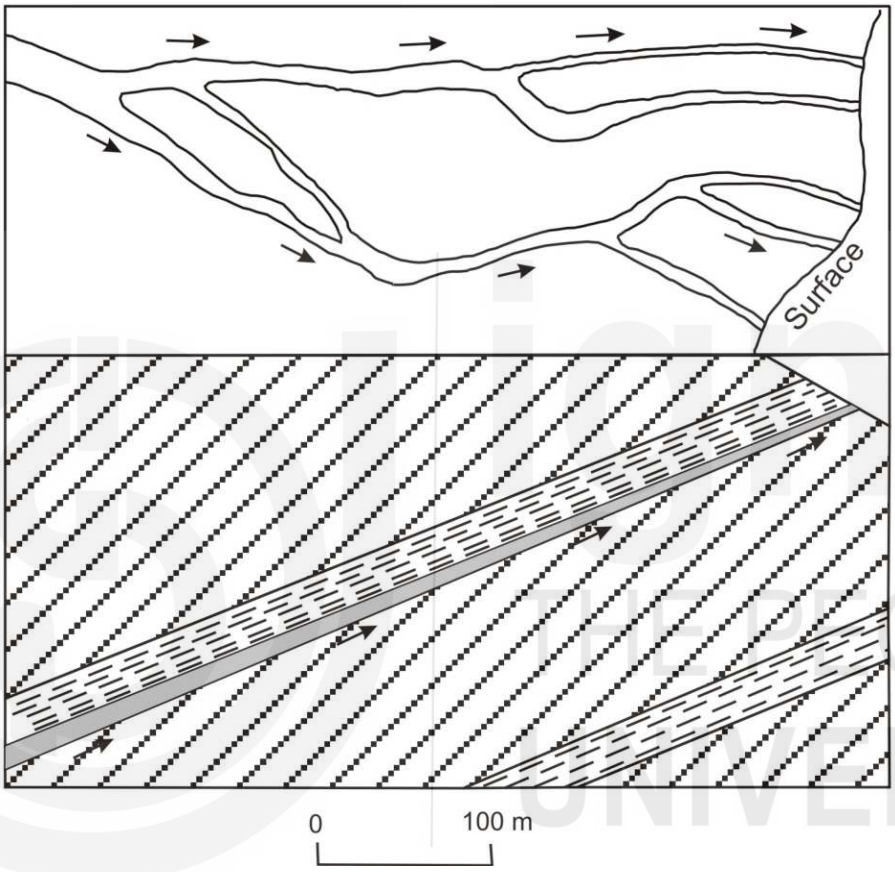


Fig. 11.8: Cross section showing tubular ore bodies. (Source Alexander, 2009)

B) Irregular Shaped Ore Bodies

i) **Disseminated deposits**: When the ore minerals are scattered throughout the body of the host rock they are known as disseminated deposits. Disseminated accessory minerals like zircon or apatite in the igneous rocks can be considered as analogy to recognise them. Disseminated deposits may wholly occur along close-spaced veinlets cutting the host rock and form an interlacing network called **stock work** (Fig. 11.9 and 11.10). This type of mineralisation generally fades gradually outwards into sub-economic mineralisation and the boundaries of the ore body are assessing limits irrespective of mode of occurrence. They are often irregular in form ore body may cut across the geological boundaries. The overall shapes of some are cylindrical and cap like. Stock works occur most commonly in felsic to intermediate plutonic igneous intrusions, but they may cut across the contact (Figs. 11.9 and 11.10) into the country rocks. World's copper and molybdenum deposits occur as disseminated deposits.

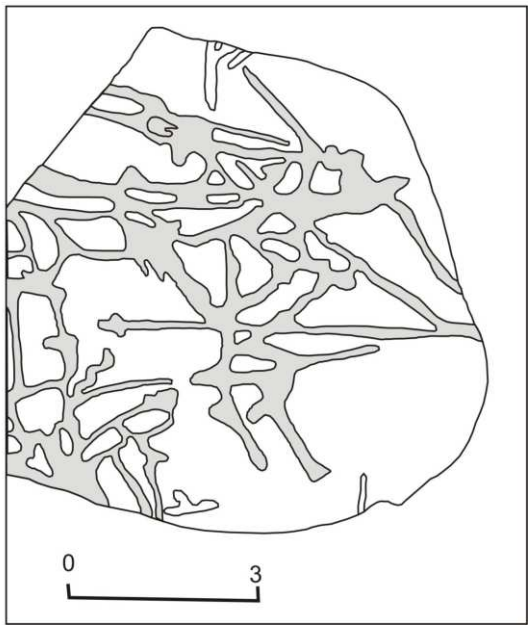


Fig. 11.9: Stock work of ore bearing quartz veinlets in granite. (Source: Alexander, 2009)

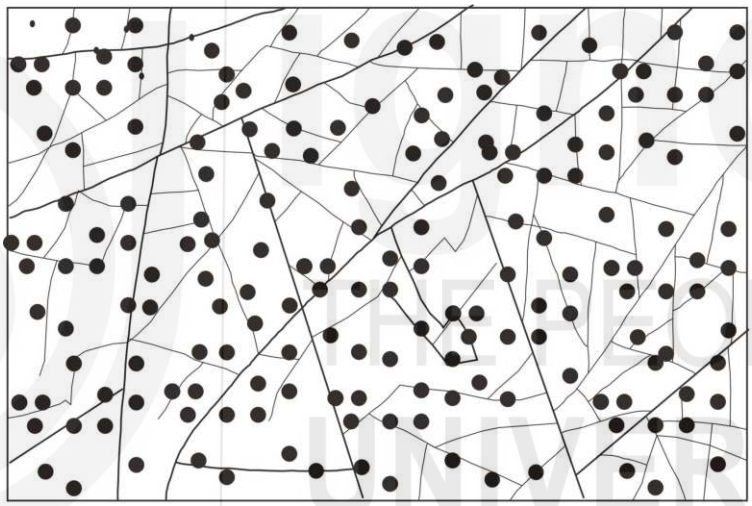


Fig. 11.10: Sketch of stock work showing the occurrence of disseminated ore bodies in the form of veinlets. (Source: Alexander, 2009)

ii) **Irregular replacement deposits**: They are the ore deposits formed by the replacement of pre-existing rocks carbonate rich sediments (e.g. magnesite deposits). These replacement processes often occur at high temperatures, contacts with the medium to large size igneous intrusions. Such deposits have therefore been called contact metamorphic or pyrometasomatic deposits; however, **skarn** is a more popular term. You will read about them in Unit 12 of this course.

11.5.2 Concordant Ore Bodies

We can classify them depending upon their host rock which can be of igneous, sedimentary and metamorphic origin.

Concordant ore bodies in sedimentary rocks are very important for several different metals, e.g. base metals and iron ore deposits. As the name implies they are concordant or parallel with the bedding. They can be an integral part of the

stratigraphical sequences, as is the case with Phanerozoic ironstones. They may be epigenetic infillings of pore spaces or replacement ore bodies. Usually these ore bodies show a considerable development in two dimensions, i.e. parallel to the bedding with limited development perpendicular to it. Therefore, these deposits are also referred as **stratiform**. These deposits are concentrated within one or more strata of volcano-sedimentary and sedimentary rock formations. This must not be confused with stratabound. **Stratabound** refers to any type(s) of ore body, concordant or discordant, which are restricted to particular stratigraphic column.

A) Sedimentary Host Rocks

Now we can categorise the sedimentary host rocks depending on their origin as follows:

i) **Limestone host rock**: Limestone is very common host rocks for base metal deposits. They often provide zones in which permeability has been increased by dolomitisation or fracturing. Limestone because of their solubility and reactivity can become favourable horizons for mineralsation.

ii) **Argillaceous host rock**: Shale, mudstone, argillite and slate are important host rocks in case of concordant ore bodies. For example, Kuperschiefer deposit of Germany has Upper Permian shale as host rock. World's largest, single lead-zinc ore body occurs at Sullivan, British Columbia wherein the host rocks are Late Precambrian argillites.

iii) **Arenaceous host rock**: Some ore bodies occur in altered feldspathic sandstones such as in the Mufulira copper deposit in Proterozoic rocks of Zambia (Fig. 11.11).

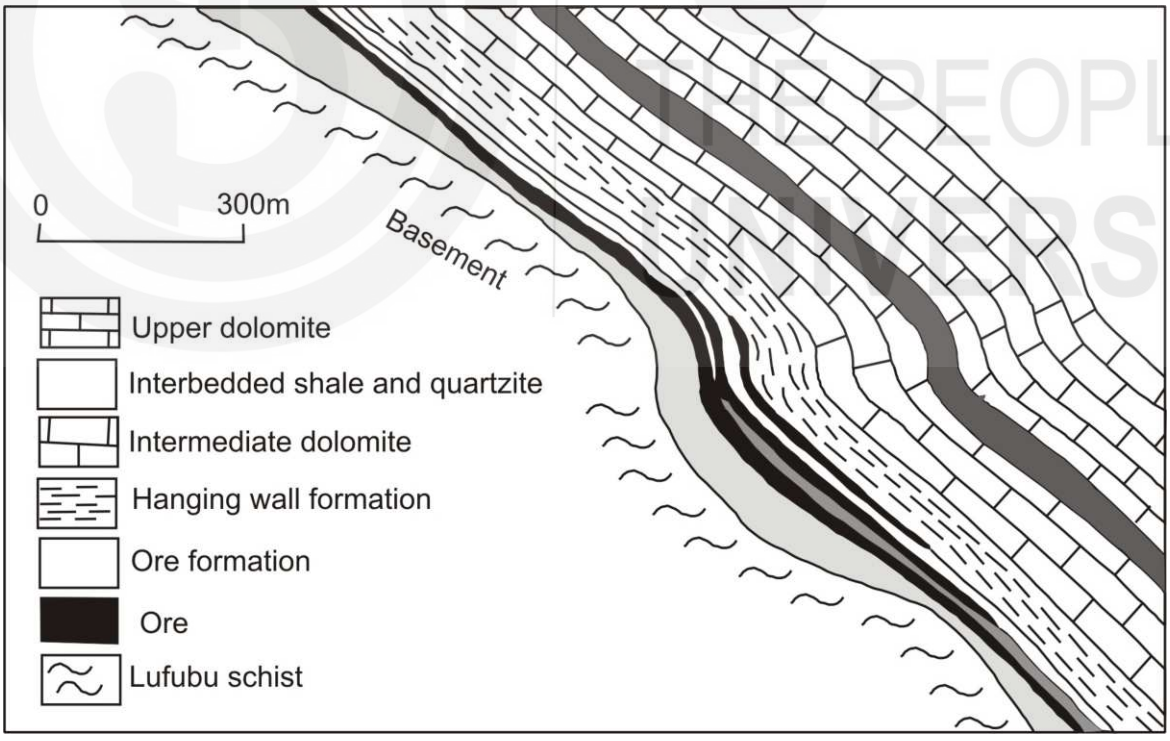


Fig. 11.11: Mineralisation in arenaceous host rocks. Cross section through the Mufulira ore bodies, Zambia. (Source: Alexander, 2009)

iv) **Rudaceous host rock**: Alluvial gravels and conglomerates also form important recent and ancient placer deposits. World's gold is found in Precambrian deposits of this type occurs in famous Witwatersrand goldfields in South Africa. Uranium is recovered as a byproduct.

v) **Chemical sedimentary host rocks**: Sedimentary iron, manganese, evaporates and phosphorite deposits occur scattered throughout the stratigraphical column forming very extensive beds.

B Igneous Host Rocks

We can classify igneous host rock depending upon their origin, viz volcanic and plutonic origin.

i) **Volcanic host rock**: The principal type of deposits found in volcanic rocks are:

- Vesicular filling deposits, and
- Volcanic-associated massive sulphide deposits.

The vesicular filling type of deposit is not very important but the volcanic-associated massive sulphide deposits more widespread type of ore deposits (Fig. 11.12). They are generally stratiform bodies, lenticular to sheet like developed at the interfaces between volcanic units or at volcanic sedimentary interfaces.

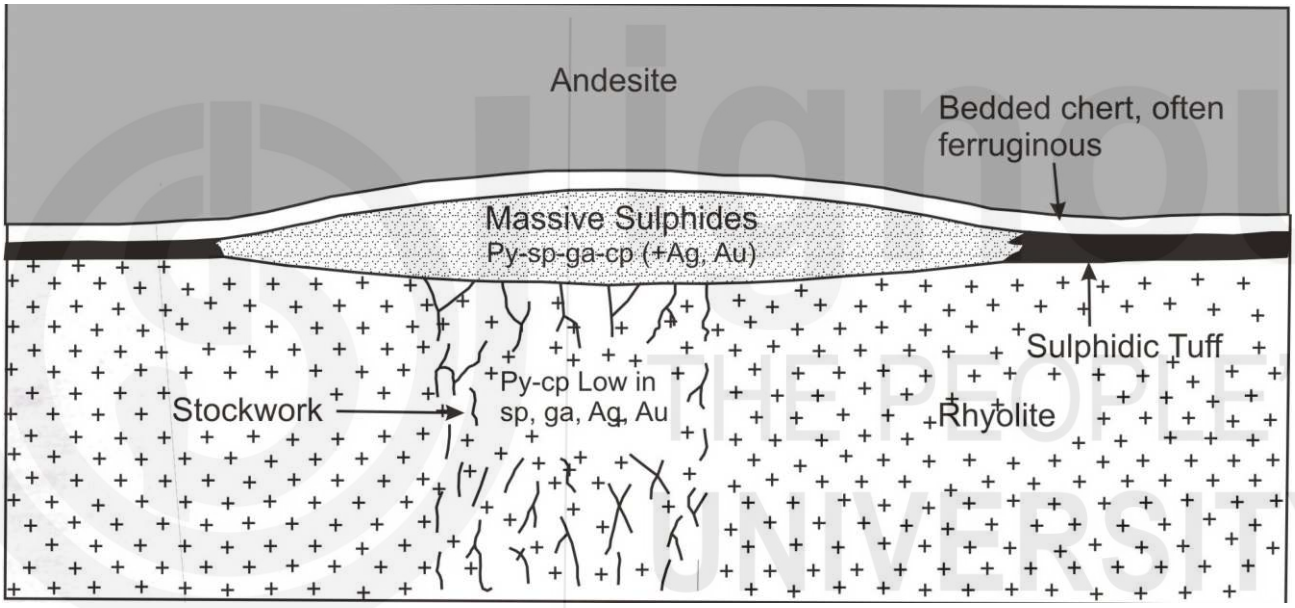


Fig. 11.12: Schematic cross section through an idealised volcanic- associated massive sulphide deposit showing underlying feeder stock work and typical mineralogy. Py=pyrite, sp=sphalerite, ga=galena, cp=chalcopyrite. (Source: Alexander, 2009)

ii) **Plutonic host rock**: Many plutonic igneous intrusions possess rhythmic layering which is particularly well developed in some mafic intrusions. Mostly layering takes in the form of alternating bands of mafic and felsic minerals. Minerals of economic interest such as chromite, magnetite and ilmenite, may form discrete mineable seams within such layered complexes. These seams are usually stratiform and extend for kilometers as in the case of the chromite seams in the Bushveld Complex of South Africa.

C) Metamorphic Host Rocks

We have already discussed about the irregular replacement deposits which can be of metamorphic origin. The deposits can be generated in contact metamorphic aureoles, e.g. wollastonite, andalusite, garnet, graphite.

11.6 ORE MINERALS

We all know that prosperity and status of a nation depends on the mineral resources as they are considered to be requisite for nation building. We have read the definitions of metallic and non-metallic ores in the Section 11.3. In this section we will read about metallic and non-metallic ore minerals.

11.6.1 Metallic Ore Minerals

Metals have always played a crucial in the evolution of our civilisation, development and industrialisation because of their unique properties. Ore is defined as a natural material or ore rock from which metals or minerals can be profitably extracted. Metallic minerals as the name suggests are mineral containing metals. The most common metals which are chemically active and commonly alloyed are called as **base metals**, e.g. copper, lead and zinc. Whereas precious metals as gold, silver and platinum are also known as **rare or noble metals**. They are commonly in demand in their native form. The term ore is applied to metalliferous minerals in a rock e. g. chromite in dunite rock or magnetite in gabbroic rock. When metallic minerals are mined they are called ores. The ores must be processed further to extract metals. First, the ore is crushed and then, the metallic minerals are separated from unwanted rock to form a concentrate. The metals in the concentrate are then separated from the non-metals. In ancient times, this process used to take place in camp fires or ovens. Today, we have smelters for this process. The concentrate is then heated to a high temperature, which releases the metals. The molten metal is then cooled.

The table 11.3 shows some important and common metallic ore minerals along with their category, composition and tenor.

Table 11.3: Common metals and their ore minerals.

SN	Metal	Ore Mineral	Category	Composition	Tenor
1	Iron	Magnetite	Oxide	Fe_3O_4	74% Fe
		Hematite	Oxide	Fe_2O_3	70% Fe
		Goethite	Hyd. Oxide	FeO(OH)	68.5% Fe
		Siderite	Carbonate	$FeCO_3$	48.3% Fe
		Pyrite	Sulphide	FeS_2	46.8% Fe
2	Manganese	Pyrolusite	Oxide	Mn_2O_3	63% Mn
		Braunite	Oxide	MnO_2H_2O	64.3% Mn
		Psilomelane	Hyd. Oxide	MnO_2	40-60% Mn
		Rhodochrosite	Carbonate	$MnCO_3$	47.8% Mn
3	Chromium	Chromite	Oxide	$Fe_2Cr_2O_4$	46.4% Cr
4	Aluminium	Bauxite	Al Hydroxide (Mixture of)	Variable	

5	Tin	Cassiterite	Oxide	SnO_2	78.8%
6	Copper	Native Copper	Native	Pure Cu	Upto 100% Cu
		Chalcopyrite	Sulphide	$CuFeS_2$	34.5% Cu
		Chalcocite	Sulphide	Cu_2S	79.9% Cu
		Bornite	Sulphide	Cu_5FeS_2	63.3% Cu
		Covellite	Sulphide	CuS	66.4% Cu
		Malachite	Hyd. Carbonate	$Cu_2CO_3(OH)$	57.4% Cu
		Azurite	Hyd. Carbonate	$Cu_2CO_3(OH)_2$	55.3% Cu
7	Load	Galena	Sulphide	PbS	86.6% Pb
8	Zinc	Sphalerite	Sulphide	ZnS	67.1% Zn
		Smithsonite	Carbonate	$ZnCO_3$	52% Zn
9	Nickel	Pentlandite	Sulphide	(Fe,Ni)S	
		Nicolite	Arsenide	NiAs	
10	Sulphur	Arsenopyrite	Sulphide	FeAsS	46.0% As
		Orpiment	Sulphide	As_2S_3	61% As
		Realgar	Sulphide	As_2S_2	70.1% As
11	Gold	Native gold	Native	Au. Ag	80-98 % Au

11.6.2 Non-Metallic Ore Minerals

You have read in the previous section that non-metallic minerals are considered as industrial minerals rather than ores. **Industrial minerals** can be defined as any Earth material of economic value which is not a metal, ore or fuel. Gypsum, clays, barite and fluorite, magnesite, asbestos, mica, talc (Fig. 11.13) are some of the common industrial minerals. They form important constituents of manufactured products, or they are employed in the production of other industrial products. The non-metallic mineral resources are mainly processed by physical methods as compared to metals. Several metallic ore minerals such as chromite, bauxite and rutile also have industrial applications however their bulk of production feeds metal industry. Most of the non-metallic minerals infact are abundantly distributed throughout the world. Their value depends less on the material itself but their proximity for usage in nearby areas. Thus largely the cost of transportation and usage determines their economic value. Mostly the non-metallic minerals are used in the form they are extracted. The gross value of all non-metallic products annually greatly exceeds that of metallic ores. Table 11.4 shows the list of common non-metallic or industrial minerals.

Table 11.4: Common non-metallic or industrial minerals

Agate	Gypsum
Andalusite	Jasper
Baryte	Kaolin
Asbestos	Laterite
Limestone	Mica
Halite	Ochre
Garnet	Pyrophyllite
Corundum	Quartz
Diaspore	Quartzite
Dolomite	Glass Sands
Graphite	Shale
Wollastonite	Magnesite
Feldspar	Slate
Fireclay	Steatite / Talc / Soapstone
Industrial Diamond	Phosphate

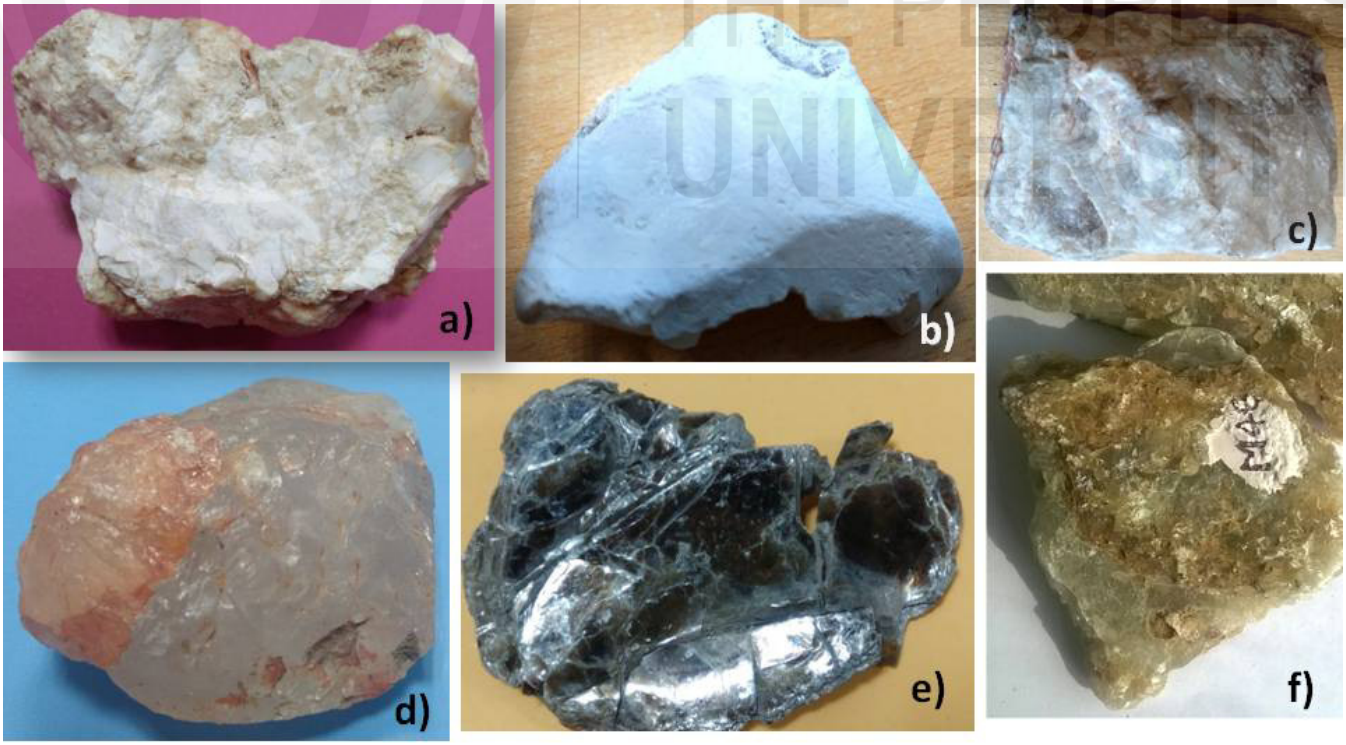


Fig. 11.13: Hand specimens of few non-metallic minerals: a) Magnesite; b) Clay; c) Barite; d) Quartz; e) Mica; and f) Gypsum.

In the previous sections, we have studied about the nature and morphology of ore deposits and metallic and non-metallic minerals. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 2

a) What do you understand by concordant and discordant ore bodies?

b) Define epigenetic and syngenetic deposits.

c) Mention about important types of host rocks for ore deposits associated with the sedimentary rocks.

d) Give names of few metallic minerals.

11.7 STRATEGIC, CRITICAL AND ESSENTIAL MINERALS

We have been introduced to metallic and non-metallic or industrial minerals. Now we will read about the strategic, critical and essential minerals. They are the outcome of emergency in relation to their supply position necessary during war. The war time is witnessed by the shooting rates of minerals, metals and other materials used for ammunitions and destructive operations on land, sea and air. The materials or minerals required during war can be categorised into two groups

- War minerals
- War supporting minerals

War minerals include those which are absolutely essential for warfare, armaments, communication and transport as they provide the fighting power at the war front. On the other hand, war supporting minerals are those which supplement the war efforts. There is hardly a mineral which can be differentiated between those required during war and those required during peace. All the minerals and metals that are needed for the production of arms and ammunitions and other equipments for fighting war are also required various machineries, plants and vehicles for usage during peace time. However the use of a particular mineral during war is quite different than in peace. The lack of particular mineral does not significantly affect us during the times of peace. But during war the lack of sufficient supply of certain minerals, even though required in a small quantity, may prove a great hazard to the security of the country.

11.7.1 Definitions

We have read about the two categories, viz. war and war supporting minerals which can further be classified depending upon total inadequacy, deficiency and sufficiency in resource position as:

- Strategic minerals
- Critical minerals
- Essential minerals

Strategic minerals are those for which a country has to depend upon outside sources as less or negligible resources available within the country, e.g. molybdenum, chromium, graphite, boron, rare earth elements, gypsum, tungsten, gold, antimony and platinum group materials.

Critical minerals are those for which a country is deficient in supply, but known occurrences are such that irrespective of the cost they can be worked during war time. The critical minerals including germanium, beryllium, rare earths (light and heavy), rhenium, tantalum etc. are used in industries like automobiles, aerospace, cameras, defence, laptops, smart phones, entertainment systems, medical imaging and nuclear energy.

Essential minerals include all those for which known resources are quite large and they are produced in sufficient quantities. It is evident that essential minerals are all those which do not fall under the category of strategic and critical minerals.

The minerals, to be categorised under each, vary for different countries. The strength of a nation depends upon how best it has developed capability of utilising its resources and processing, metallurgical and fabrication industry.

11.7.2 Applications of Minerals in War

Let us list and discuss the minerals required during war.

- Iron ore and subsidiary minerals required for the production of steel are of vital importance. Steel is the important industry as its production (takes place in millions of tons) effects all the industries.
- Manganese ore is essential for the manufacture of steel which is used in the form of ferromanganese.
- Tungsten is required for the manufacture of ammunitions, heavy guns and armour plates.
- Molybdenum is a good substitute for tungsten and is most commonly used as refractory metal as it has melting point of about 2623°C. It is one of the most important alloying elements used in steel.
- Vanadium alloys beat the best titanium alloys and gives strength to stainless steel.
- Cobalt is one of the ferro alloy metal which improves the magnetic qualities in iron. It is used in the electronic industry for producing permanent magnets.
- Antimony is used in the manufacture of antifriction metals and hardening of lead required for making shrapnel (fragments of a bomb, shell, or other object thrown out by an explosion).
- Cadmium is used in the processing of uranium and in the manufacture of special steel. Magnesium is used for making light metal alloys for planes, automobiles and trains.
- Zirconium alloyed with steel was used to manufacture a number of equipments during the last world war.

- Aluminum came into market in commercial quantity in 1939. Since then it has caught up rapidly as light structural metal for military use. Its abundance has replaced copper, lead, zinc, tin and also steel to great extent.
- Beryllium metal is used extensively as a moderator in atomic piles and nuclear reactions. It has a property of slowing down neutrons without absorbing them. Beryllium and copper alloys develop a high tensile strength and ability to withstand repeated stress.
- Mica is very useful for its dielectric and insulating properties. It is used in the manufacture of electronic equipment.
- Piezoelectric quartz crystals and mica have a great significance in radio, telecommunication and electronic industry.
- Germanium metal has led to the invention of transistorised radio communication. With the use of this metal, it has been possible to make smallest sets which can be carried even in pockets for communicating between the army in front.
- Sulphur is used in the manufacture of so many products which help to mobilise essentials of war.
- Phosphorous is used in manufacture of inflammable bombs, bullets, smoke screens. Lithium and its compounds, after the Second World War, have become important during war and peace times.
- Strontium compounds have many war time applications. Strontium oxalate finds use in tracer bullets to control the burning rate of the trace composition.
- Uranium is known for its destructive power and also possess tremendous power for peaceful purposes.

Now, it may be understood that all the minerals cannot be grouped into war group. There are few number of minerals whose presence or absence may not effect the war period. These are diaspore, pyrophyllite, garnet, ochre, chalk, wollastonite, precious stones (excluding industrial diamond), etc. Some minerals belonging to the group of aluminosilicate, e.g. kyanite, sillimanite and andalusite, may not attract much military significance.

11.8 SUMMARY

In this unit we have discussed about ore, its concept, morphology of ore deposits and metallic and non-metallic minerals. Now let us summarise about what we have learnt in this unit:

- Economic geology covers all aspects pertaining to description and understanding of mineral resources.
- Ore is defined as a naturally occurring mineral or aggregate of minerals from which metal(s) could be extracted with profit. Gangue minerals comprise all non-economic, unwanted, worthless, metallic or non-metallic materials or minerals associated with an ore. Host rock surrounds the ore and gangue and like gangue it has no commercial value. Ore deposits or mineral deposits are natural concentrations of useful minerals or rocks, which can be economically exploited.

- Industrial minerals have been defined as any rock, mineral or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels and gemstones.
- Tenor is the actual metal content present in an ore. Ore grade is used in the commercial classification of ores which takes into account the chemical and physical properties of an ore.
- Clarke value refers to the average abundance of a particular element in the Earth's crust; Clarke values are synonymous with the crustal abundances. Clarke of Concentration (KK) is the concentration of an element in a particular rock compared with its average concentration in the Earth's crust, or of an element within a particular mineral.
- Syngenetic deposit is the ore deposit which has formed by the same process and at the same time as the enclosing rock. Epigenetic deposit is the ore deposit which has formed after the formation of the host rock in which they occur.
- Discordant ore body refers to ore body which cuts across the bedding plane or banding. They can be regularly shaped ore bodies forming tabular and tubular ore bodies. While irregularly shaped ore bodies grouped as disseminated deposits and irregular replacement deposits.
- Concordant ore body refers to ore body which is parallel to the lithological bedding plane or banding. The host rock can be sedimentary, igneous and metamorphic.
- The most common metals which are chemically active and commonly alloyed are called as base metals. Minerals can also be classified depending upon total inadequacy, deficiency and sufficiency in resource position as strategic minerals, critical and essential minerals.

11.9 ACTIVITY

- List the minerals and metals used in manufacture of a bulb.
- Find out the metallic and non-metallic minerals mined in your state. You can take help of the websites of Geological Survey of India, Indian Bureau of Mines and Directorate of Geology and Mining of your state.

11.10 TERMINAL QUESTIONS

1. What is an ore? How would you explain ore or ore deposit with the help of Clarke and Clarke of concentration values?
2. How and when the terms essential strategic and critical minerals have evolved? What are the strategic minerals for India?
3. What are the important morphological features of sulphide ore bodies?
4. Give a list of common metals and their ores.

Audio/video material based questions

- Discuss briefly the historical classification of ore deposits.
- List the agencies responsible for formation of ore deposits.
- What are the sedimentary types of ore deposits?

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11.13 ANSWERS

Self Assessment Questions

1. a) The minerals having appreciable concentration of metallic elements, viz. Fe (iron), Mn (manganese), Cu (copper), Au (gold), Ag (silver) and Pb (lead) are called as metallic ore minerals. The non-metallic minerals are considered as industrial minerals rather than ores. Industrial minerals have been defined as any rock, mineral or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels and gemstones.

   b) Economic Geology is a sub discipline of the geology which devotes itself to the scientific study of the Earth's sources of mineral raw materials (used for economic and/or industrial purpose) and to the practical application of the acquired knowledge. It leads in the search of new mineral deposits and in their detailed investigations.

   c) Ore is defined as a naturally occurring mineral or aggregate of minerals from which metal/metals could be extracted with profit. It usually occurs with useless gangue mineral or mineral aggregates, substance or unwanted substance. While the gangue minerals comprise all of non-economic, unwanted, worthless, metallic or non-metallic materials or minerals associated with an ore.

   d) Endogenous processes include magmatic concentration, sublimation, contact metasomatism and contact metamorphism and pegmatite / pneumatolytic processes.

   e) Exogenous processes include oxidation and supergene enrichment deposits, evaporation, residual and mechanical concentration and metamorphism

2. a) Concordant ore body is parallel to the lithological bedding plane or banding whereas discordant ore body can defined as the ore body which cross cuts the lithological bedding plane.

   b) Syngenetic deposit is the ore deposit which has formed by the same process and at the same time as the enclosing rock in which it occurs. Epigenetic deposit is the ore deposit which has formed after the formation of host rock in which they occur.

   c) Limestone, argillaceous, arenaceous, rudaceous and chemical sedimentary rocks

   d) Fe (Iron), Mn (manganese), Cu (copper), Au (gold), Ag (silver), Pb (lead), Zn (zinc), Ni (nickel), Co (cobalt), Sn (tin), W (wolframite), V (vanadium) are called as metallic ore minerals.

Terminal Questions

1. Please refer to subsection 11.3.2 and 11.3.3.
2. Please refer to section 11.7.
3. Please refer to section 11.5.
4. Please refer to the table 11.3.

UNIT 12

PROCESSES OF ORE FORMATION

Structure

12.1 INTRODUCTION

You have been introduced to ore and ore deposits in the previous unit. Now in this unit, you will learn about the geological processes that have played important role in the formation of different metallic and non-metallic deposits. Magmatic processes, heat, pressure, chemically active fluids, chemical reactions, weathering, erosion, transport, deposition and

biota, all have contributed in the generation of economic mineral deposit. All these processes have worked and are working independently or in combination throughout the geological period. There must have been several constraints which explain as to why mineral deposits are such a rare commodity. Now we will discuss in detail about the processes of formation of ore deposits.

Expected Learning Outcomes

After reading this unit, you should be able to:

- define the various processes of formation of ore deposits;
- acquaint with the basic terminology related to ore deposits;
- classify and list the ore forming processes;
- explain the endogenous ore forming processes such as magmatic concentration, sublimation, pegmatite / pneumatolytic, hydrothermal, contact metasomatism and metamorphism and metamorphism; and
- discuss the exogenous processes of ore formation such as sedimentation, residual and mechanical concentration, oxidation and supergene enrichment , evaporation and syn-sedimentary volcanogenic processes.

12.2 FACTORS CONTROLLING AVAILABILITY OF ORE DEPOSIT

In this section, we will be read about the factors controlling availability of ore deposit. Mineral concentration in the crust of the Earth is produced by the interplay of various geological processes. However, even if rich mineral deposit is located and explored, it may not be exploited till several vital factors are satisfied. The main factors controlling the availability of mineral deposits (Kesler, 1994) in this sense are: geological, engineering, environmental and economic.

Geological factors: The crustal rocks exhibit minute concentrations or quantities of all the metals. Such crustal abundance of metals is expressed in Clarke values, which represents a ratio of a particular element in a rock to the average amount of the element in the Earth's crust. Recall that we have learnt about Clarke values in the previous unit. Different geological processes like magmatism, sedimentation, and metamorphism concentrate such discrete metals present in crustal rocks in specific geological settings to form a rich ore deposit. For example- Earth surface processes like weathering and erosion, operating on a country rock bearing discrete amounts of gold concentrate to form an economically exploitable placer deposit. Thus geological factors play a dominant role in the concentration and availability of mineral deposits. Ore deposits form when a useful commodity is sufficiently concentrated in an accessible part of the Earth's crust so that it can be profitably extracted. It is important to consider the range of concentration and the factors that characterise the formation of different types of ore deposit. Some of the strategically important metals, such as Fe, Al, Mg, Ti, and Mn, are abundantly distributed in the Earth's crust (i.e. between about 0.5 and 10%) and only require a relatively small degree of enrichment in order to make a workable deposit. Now it is clear to us that the economics of mining dictate that these metals need to be concentrated by factors in the hundreds in order to form potentially viable deposits. The degree of concentration required for the precious

metals is even more demanding, where the required enrichment factors are in the thousands.

Engineering factors: Engineering constraints also play a vital role in exploitation even though a mineral deposit is identified. Economically viable ore deposit may not be workable unless certain engineering parameters are satisfied. For example, advanced countries do not allow deposits to be worked at depths greater than about 4 km, while the deepest oil wells are about 8 km deep. Any resource beyond these limits is unavailable for exploitation. For example, the Kolar gold mine (Champion Reef) was closed down because it was not economically viable to mine at depths of 3.4 km where a huge expense was borne for airconditioning of the mines.

Environmental factors: They also play an equally vital role in the exploitation of a known ore deposit. A large deposit of uranium has been located and explored in recent years in Srisailam area of Andhra Pradesh. However, this deposit has not been given environmental clearance for mining by the Ministry of Environment and Forests because it is located within the Rajiv Gandhi Tiger Reserve. No matter how good known mineral resource is available for exploitation the clearance will not be given clearance for mining if environmental degradation assessed is too high.

Economic factors: Mineral economics play the most crucial role in the exploitation of a resource. The ore deposit should be profitably exploitable. However, exception may be there in the case of strategic minerals. They can be mined at a time of emergency, like, war, without considering economic factors. The price of the commodity effectively regulates the cost of mineral production. Even for a good deposit with high grade and reserve, if the cost of extraction, beneficiation and environmental protection is too high, it may not be open to mining at a particular point in time when it might be cheaper for a country to import that metal from abroad. Demand and supply is also an important factor controlling the cost of mineral production.

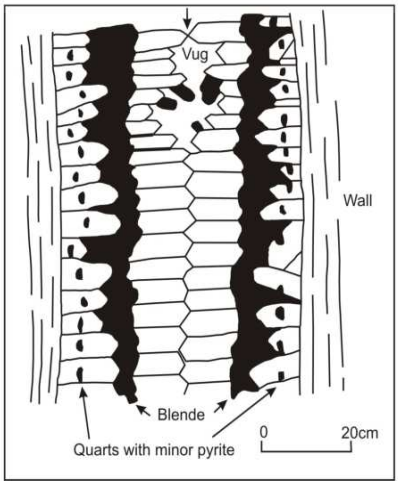
12.3 BASIC TERMINOLOGY

Let us learn some basic definitions related to ore forming processes and deposits. Let us recall the definitions of syngenetic and epigenetic ore deposit that we have read in previous unit.

- **Syngenetic deposit**: It refers to ore deposits that form at the same time as their host rocks. These are formed contemporaneously with the enclosing or host rocks.
- **Epigenetic deposit**: These are formed later than the rocks that enclose them. They are deposited in openings present in the rocks, or by the process of replacement.
- **Hypogene**: It refers to mineralisation caused by ascending hydrothermal solutions.
- **Supergene**: It refers to mineralisation caused by descending solutions. Generally it refers to the enrichment processes accompanying the weathering and oxidation of sulfide and oxide ores at or near the surface.
- **Metallogeny**: It is the study of genesis of mineral deposits, with emphasis on their relationships in space and time to geological features of the Earth's crust.

- **Metallotect**: It refers to any geological, tectonic, lithological, or geochemical feature that has played a role in the concentration of one or more elements in the Earth's crust.
- **Metallogenic epoch**: It refers to a unit of geologic time favourable for the deposition of ores. In other words, it is the geological period which is characterised by a particular assemblage of a mineral deposit.
- **Metallogenic province**: It is a region characterised by a particular assemblage of mineral deposit types.
- **Banded ore**: It is ore composed of bands or layers. The layers may be composed of the same minerals differing in colour, texture and proportions. They may also be composed of different minerals (Fig. 12.1a).
- **Crustification or crustified vein:** The banding is produced when mineral layer of character are deposited successively one upon another on the borders of openings. In the comb structure, elongated prisms project approximately at right angles to a surface, like teeth of a comb (Fig. 12.1b & c).
- **Vein material:** It is the matter that constitutes veins, whether ore or gangue. It can be workable or not workable.
- **Gouge**: It is the soft clay-like material that occurs at some places as a selvage between a vein and country rock. It is usually formed by the crushing of ore or country rock or both.

(a)



(b)

(c)

Fig 12.1: a) Hand specimen of banded hematite quartzite; b) Longitudinal section across a vein showing crustified banding; (Source: Alexander, 2009) **and c) Crustified vein.**

12.4 INTRODUCTION TO PROCESSES OF ORE FORMATION

The processes of formation of ore deposits are very complex. There are several types of deposits, generally containing several ore and gangue minerals. No two ore deposits are alike; they differ in mineralogy, texture, content, shape, size and other features. They are formed by diverse processes. We can group all the ore forming processes which fall in two broad categories:

- Primary or hypogene or endogenous (high P-T conditions)
- Secondary or exogene or exogenous (Fig. 12.2).

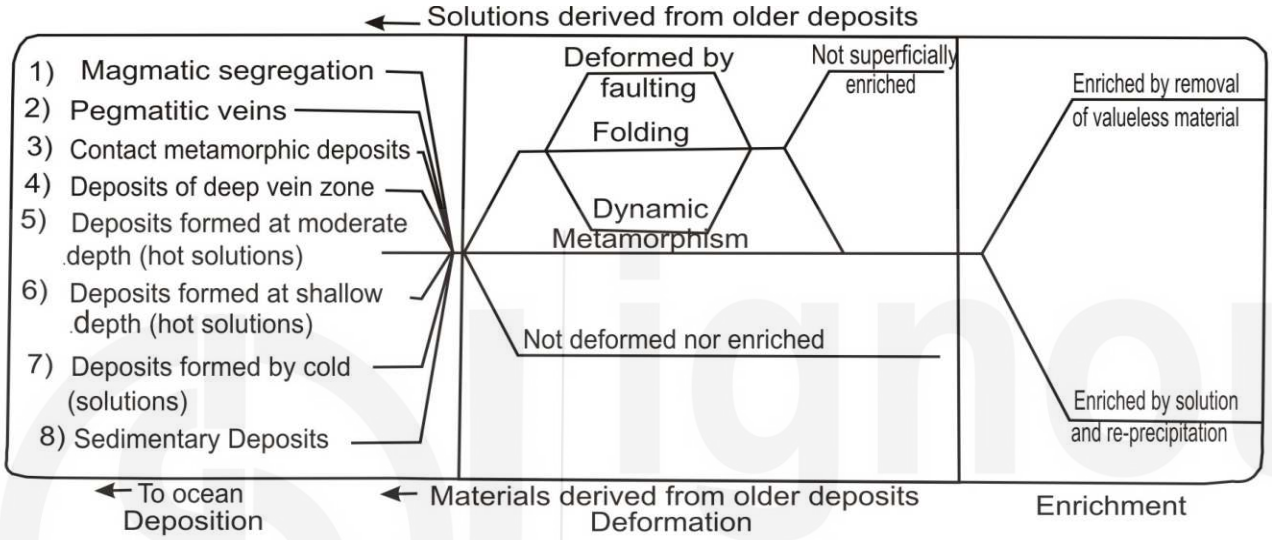


Fig: 12.2. Diagram illustrating the mode of deposition, deformation and enrichment of various ore deposits. (Source: Emmons, 1940)

The endogenous and exogenous processes are listed as given below:

A) Endogenous Processes (also known as primary or hypogene)

- Magmatic Concentration

  The minerals of economic importance in igneous rocks are crystallised prior or post to rock forming minerals or silicate minerals. On the basis of this magmatic concentration processes can be classified into two:

  a) Early Magmatic

  b) Late Magmatic

- Sublimation
- Pegmatite / Pneumatolytic
- Hydrothermal
- Contact Metamorphism and Metasomatism
- Metamorphism

B) Exogenous Processes (also known as secondary or exogene)

- Sedimentation
- Residual and Mechanical Concentration
- Oxidation and Supergene Enrichment

- Evaporation
- Bacteriogenic Precipitation
- Syn-sedimentary Volcanogenic

12.5 ENDOGENOUS PROCESSES OF ORE FORMATION

The endogenous processes extend downward from the lower levels of circulating meteoric water to the deepest level at which rocks are formed. It is an environment of high temperature and pressure, restricted circulation of fluids, and relatively low free oxygen content.

Now let us discuss the endogenous processes.

12.5.1 Magmatic Concentration

Magma is the primary and ultimate source of all kinds of deposits. Magmatic deposits result from simple crystallisation and concentration by differentiation of intrusive igneous masses. The host rock for the formation of ore deposit ranges from ultramafic to felsic igneous rocks. In order to understand the magmatic processes it is necessary to understand at the physico-chemical environment which tells us about the conditions of ore formation. The source of material (molten rock material-magma) for magmatic concentration process is located at great depth. Temperature and pressure is dependent on the depth:

- Pressure range: The stability field for diamond and pyrope is 150 km to 1 km depth.
- Temperature range: Formation of diamond takes place at 1500ºC and sulphide ore at 300ºC.

Magmatic ore deposits are also called as **magmatic segregation**, **magmatic injection**, or **igneous syngenetic deposits**. Magmatic ores deposited by magmatic activity are also known as **orthomagmatic ore deposits**. These types of deposits result in massive ores and in some cases they may be disseminated. Diamonds occur as crystals in the rocks known as kimberlite (found in South Africa, Australia, India) fall under the category of **magmatic disseminated** type of deposits. Diamonds are crystallised deep within the magma chamber and are later transported upwards. There are several modes of formation of magmatic deposits. Magmatic ore deposits originate during different phases of magma crystallisation. **Early magmatic deposits** result during early phase of crystallisation of magma. While during late phase of crystallisation the immiscible liquids give rise to mineral deposits known as **late magmatic deposits**. Let us discuss in detail about them.

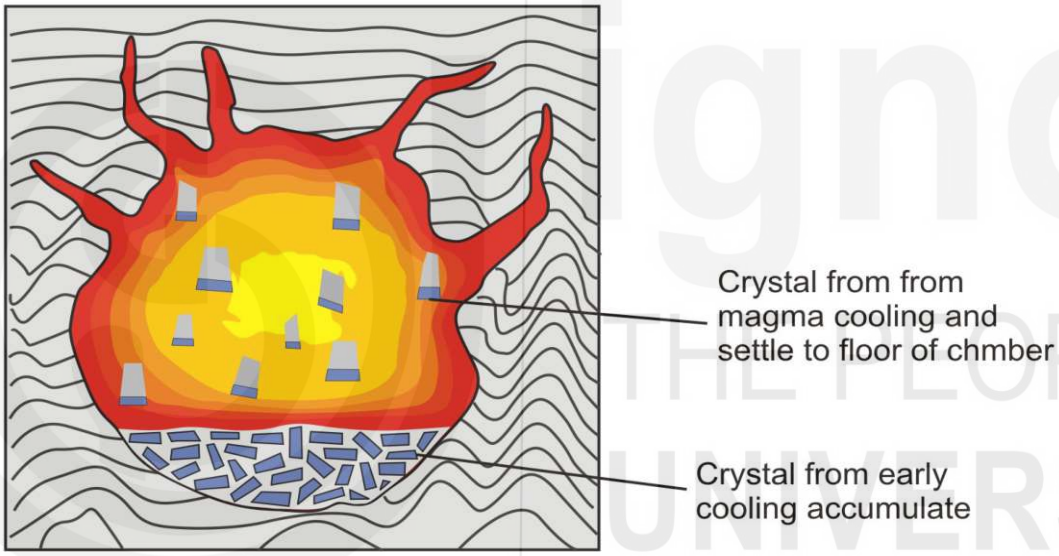
A) Early Magmatic Processes: As discussed above the early magmatic deposits result during early phase of crystallisation of magma and can be formed by:

- Dissemination or Magmatic crystallisation without concentration
- Segregation of early formed crystals during crystallisation, and
- Injection of magmatic material concentrated at some other place by differentiation.

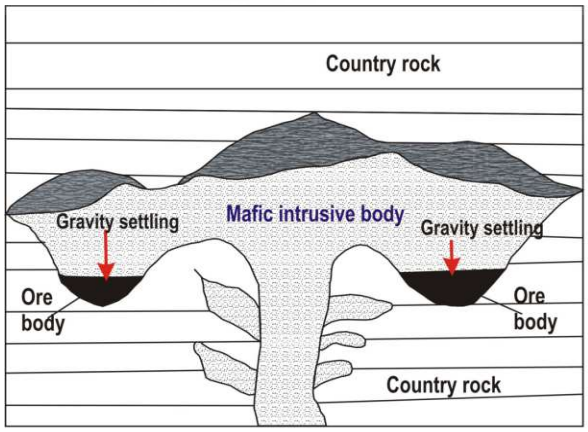
Dissemination: During the deep seated crystallisation granular rock is formed in which the early formed crystals disseminate and give rise to ore body. Disseminated or

scattered ore deposits are formed due *in situ* crystallisation of magma in plutonic conditions. Example: Majhgawan (Panna, Madhya Pradesh) is famous for diamond deposit in Kimberlite rock.

Segregation: As the magma start cooling, the ore minerals crystallise during early stage and being denser they sink down to the magma chamber by the process of **gravity settling** (Fig. 12.3a and b). In this process Early magmatic minerals crystallise due to concentration are form important deposits due to concentration by gravitative crystallisation and differentiation. Example: chromite deposit in India is formed in Sukinda Complex, Singhbhum. Thus the ore and common minerals crystallise at similar temperatures and accumulate as layers at the bottom, forming a rich deposit called as early magmatic deposit. Bushveld intrusion in South Africa is the best example, where a large volume of magma intruded into older sedimentary rocks forming a saucer shaped body. **Magmatic segregation** is a general term which refers to any process by which one or more minerals become locally concentrated (segregated) during the cooling and crystallisation of magma. Mineral formed as a result of magmatic segregation are called as **magmatic cumulate** (Fig. 12.3c).



(a)



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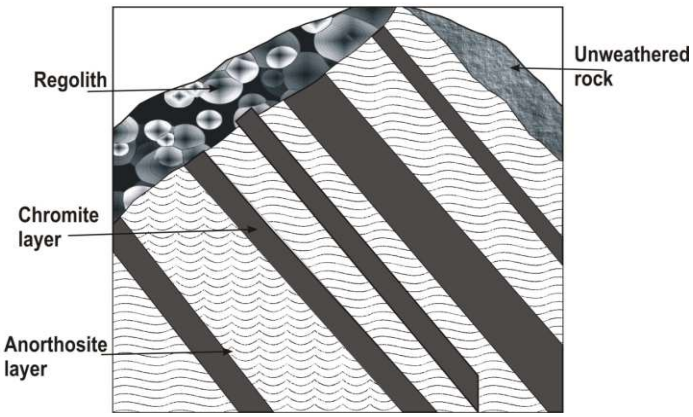


(c)

Fig. 12.3: a) Early formed crystals may sink and accumulate in the magma chamber as the result of gravity settling; b) Formation of ore body by gravity settling process; and c) Cumulate structure due to magmatic segregation, notice parallel chromite (black) and anorthosite (white stippled).

Injection: During crystallisation if the early formed crystals are segregated and thereafter injected into parent rocks or country rocks, then these deposits are known as injection deposits. The crystallisation and segregation of this category of deposits takes place in the magma chamber, but they are found elsewhere. The relationship of this type of deposits with the country rocks can be concordant or discordant. Example: Kiruna magnetite deposit in Sweden.

Watch the following video to more about early magmatic processes.

- **Early magmatic deposits**

  Link: http://egyankosh.ac.in//handle/123456789/53456

B) Late Magmatic Process: Ore deposits formed towards the end stages of crystallisation of magma are termed as late magmatic deposits. They are formed from the remaining melt towards the later phase of magmatic crystallisation. The ore minerals crystallise after the formation of host rock as a result ore bodies cut across the rock formation. These deposits are associated with plutonic hypabyssal rocks. During the late phase of magmatic crystallisation when the residual liquid become enriched in iron, titanium and volatiles and settle to the bottom of the magma chamber, or crystallises in the interstices of early formed crystals. The late magmatic deposits result from mechanical processes like:

- Residual Liquid Segregation
- Residual Liquid Injection
- Immiscible Liquid Segregation
- Immiscible Liquid Injection

1) **Residual Liquid Segregation:** Commonly the residual magma after magmatic differentiation is rich in silica and water. After the differentiation of ultramafic magma iron and titanium remain in residual liquid. This residual liquid is separated from rest of the magma and crystallises in the form of mineral ore deposit. The prerequisite for the formation of ore deposit is that during crystallisation those parts of the Earth should not undergo disturbances. Example: titanium rich magnetite deposits of Bushveld Complex, South Africa.

2) **Residual Liquid Injection:** After the process of residual liquid segregation the residual liquid is injected in host rock or country rocks and the formation of residual liquid injection deposits takes place. Earth disturbances play an important role in the formation of the mineral deposits. Residual liquid is injected into areas of low pressure due to Earth disturbances. Commonly these deposits are irregular in shape, in the form of a wall or sill. The formation of magnetite and ilmenite takes place by the process of residual liquid injection. Example: Adrinodack magnetite and ilmenite deposit, USA and big magnetite deposit in Kiruna.

3) **Immiscible Liquid Separation:** Metals like copper and nickel play significant role in the formation of sulphides. The differentiated rocks of gabbro family have sulphides of nickel and copper along with metals like gold, silver, platinum. In the ultramafic magma the sulphides of iron, copper and nickel being immiscible and heavy accumulate at the bottom of the magma chamber. The sulphide minerals are crystallised after the crystallisation of rock-forming silicate minerals. Commonly this category of deposits include pyrrhotite, chalcopyrite, pentlandite in which apart

from nickel and copper ore deposits platinum, silver and other metals are found in low concentrations.

4) **Immiscible liquid injection:** Immiscible liquid after differentiation is accumulated in the magma chamber can be injected elsewhere due to Earth disturbances. These injected sulphides after cooling form immiscible liquid injection deposits. The shape of the deposit can be irregular or wall like and in these deposits the fragments of previously formed rock-forming minerals and rocks are found. They are found as discordant structure. Commonly sulphide of metals are found in these deposits.

- Watch the following video to more about late magmatic processes.

  Late magmatic deposits

  Link: http://egyankosh.ac.in//handle/123456789/53457

The metals and minerals ores found as the result of magmatic concentration are as follows:

- Native: Platinum, gold, silver and copper
- Oxide: Magnetite, titanium bearing magnetite, ilmenite, chromite and corundum
- Sulphide: Chalcopyrite, pyrrhotite, pentlandite and bornite
- Gemstones: Diamond, garnet and peridot

These are some minerals which are found in specific rocks or group of rocks as the result of magmatic concentration process. The intimate relation between mineral ores and rocks is as follows:

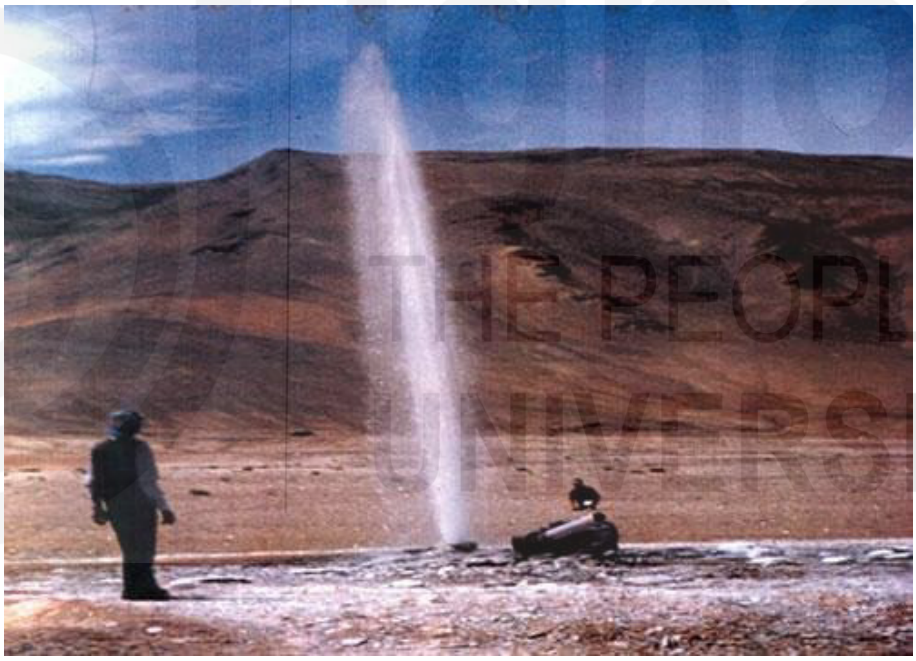
- Diamond – Kimberlite
- Chromite – Peridotite, dunite
- Nickel – Copper deposit, norite
- Platinum – Norite, peridotite

12.5.2 Sublimation

After having learnt about processes of formation of ore deposits by magmatic concentration let us learn about the process of sublimation.

Sublimation is a subordinate process of the formation of mineral deposits. It applies only to compounds that are volatilised and subsequently re-deposited from vapour at lower temperature or pressure. It involves direct transition from the solid to the gaseous state, or vice versa, without passing through the liquid state. The process is often associated with volcanism and fumaroles. There are many sublimates deposited around volcanoes and fumaroles, but they are seldom in sufficient abundance to make workable mineral deposits. Noticeable concentrations have been formed in area around geothermal springs. Sulphur deposit originated by sublimation process has been mined in many countries (Fig. 12.4a). Common sublimates are the sulphur, mercury and chlorides of iron, copper, zinc, oxides of iron and copper, boric acid, and various salts of the alkali metals and ammonium. Example-sulphur and borax deposits cover an area of 4 km^2 in the area exhibit sublimates deposited by vigorous geothermal activity in Puga valley, Ladakh (Fig. 12.4b). Occurrence of native sulphur is also reported from Barren Island in Andaman.

(a)



(b)

Fig. 12.4: a) Sulphur deposits (in yellow) formed due to sublimation process. (Source: https://upload.wikimedia.org/wikipedia/commons/4/4b/Sulfur-IMG_3733_1.JPG); **and b) Geothermal activity in Puga valley, Ladakh.** (Source: Shah et al. 2015)

12.5.3 Pegmatitic and Pneumatolytic

Pegmatites are very coarse-grained igneous rocks formed during the final stages of magmatic crystallisation. They commonly form dyke like masses of few meters (Fig. 12.5a) to occasionally 1-2 km in length. Pegmatites are associated with deep seated igneous rocks, generally with the felsic rocks, less commonly also with mafic rocks. Economic ore deposits are associated with granitic pegmatites since felsic magmas carry more water. Residual elements such as Li, Be, Nb, Ta, Sn and U that are not readily accommodated in crystallising silicate phases, end-up in the volatile fraction.

When this fraction is injected into the country rock a pegmatite is formed. The temperatures of deposition vary from 250-750ºC. You can see graphite deposition in pegmatite rock in (Fig. 12.5b).

a) (b)

Fig 12.5: a) Field photograph of pegmatite intruding granite (Photo credit: Dr. Suresh Kumar)**; and b) Graphite (shinning greyish black) deposition in pegmatitic rock.** (Source: www.usgs.gov)

12.5.4 Hydrothermal Processes

Hot ascending aqueous solutions responsible for the formation of hydrothermal ore deposits are termed as **hydrothermal solutions**. As this hot water moves into cooler regions of the crust, the dissolved minerals are precipitated from the hydrothermal solution. Hydrothermal solutions play the role of mineralisers. These hot fluids may be derived from:

- Magmatic fluids are directly associated or derived from the magma. The juvenile water which can be derived directly from magma as residual fluids towards the last stage of magmatic crystallisation when bulk of the silicate minerals have crystallised (Fig. 12.6a).
- Groundwater circulating deeper and gets heated up by coming in contact with a hot igneous body.
- Groundwater circulates to great depths gets naturally heated due to high geothermal gradient

The hydrothermal deposits result in two ways. The hydrothermal fluid can directly deposit the ore mineral from the solution in the openings or fluid which react with the enclosing country rock producing a deposit. Minerals are concentrated or deposited by hot fluids flowing through fractures, cracks, joints, fault planes/zones and pore spaces present in rocks.

Fluid inclusion research indicates most ore forming fluids range in temperature from 50ºC to 500ºC. Analysis of the fluid inclusions has shown that water is the most important phase and salinities are often much greater than those of seawater. Examples of hydrothermal deposits are: massive sulfide deposits, vein deposits (Fig. 12.6b), and stratabound mineral deposits. On the basis of temperature and pressure of formation, hydrothermal deposits are classified into the following types:

- **Hypothermal deposits**: These deposits are formed at great depths near the intrusion and the temperature ranges from 300ºC - 500ºC.

- **Mesothermal deposits**: These are formed at a depth of 1500 to 4000 m below the surface and the temperature ranges from 200ºC - 300ºC.
- **Epithermal deposits**: These are formed at shallow depths away from the surface and the temperature ranges from 50ºC - 200ºC. You can see gold ore in Fig. 12.6c.
- **Telethermal deposits**: These are formed under low pressure and temperature conditions situated at a greater distance from parent igneous body without having any genetic relationship.
- **Xenothermal deposits:** These deposits are formed by high temperature ore forming fluids released from the giant igneous rock bodies which have intruded into shallow depths and they are characterised by high temperature, shallow depth of formation and high rate of cooling.

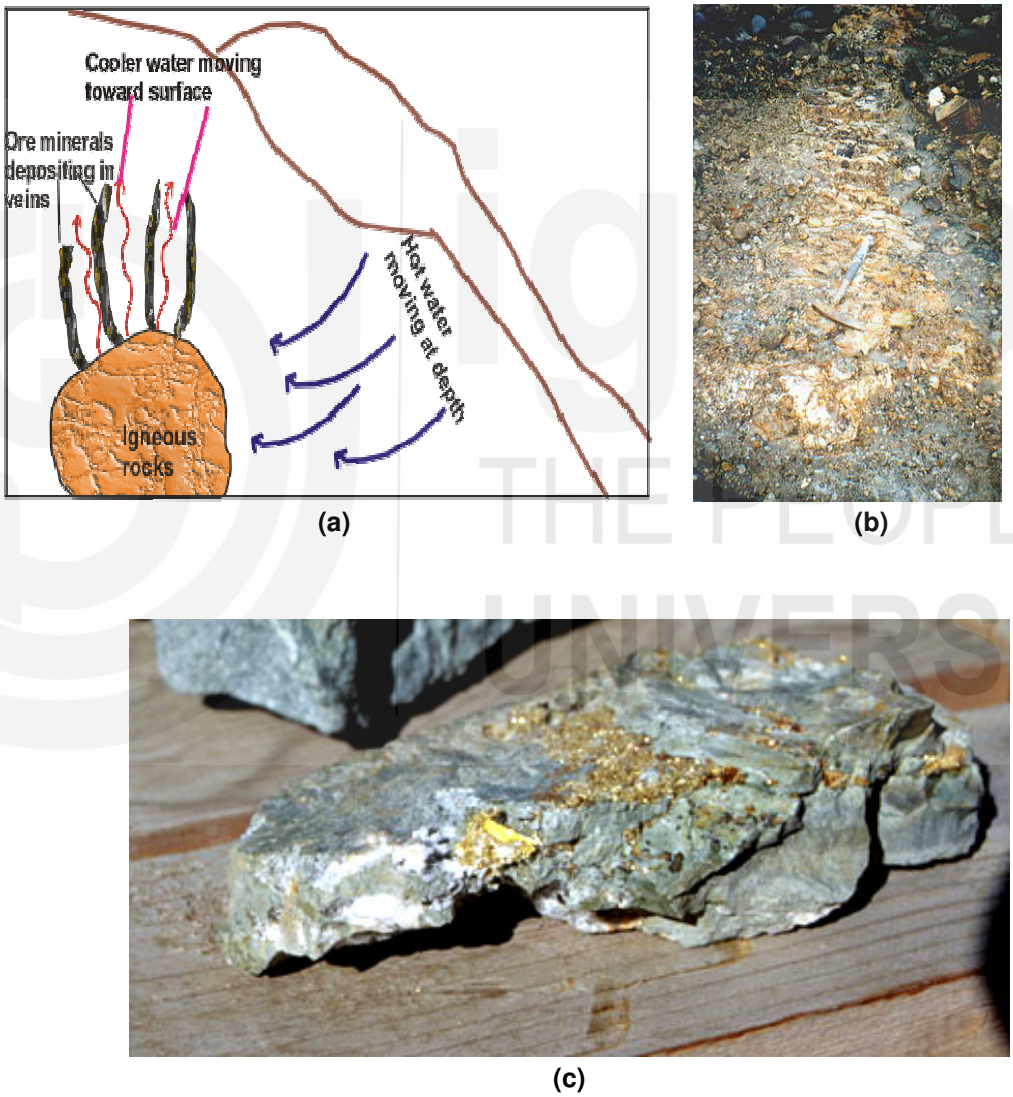


Fig 12.6: a) Cartoon showing ore mineral depositing in veins as the result of hydrothermal solutions; b) Hydrothermal deposit showing gold bearing vein; (Source: https://commons.wikimedia.org/wiki/File:Goldveins1.jpg); **and c) Gold ore from epithermal deposits.** (Source: www.usgs.gov)

The causes of hydrothermal deposition are as follows:

1. Changes in temperature;
2. Changes in pressure of the system;

3. Exchange reactions between substance in the solution;
4. Exchange reaction following mixing of solutions;
5. Exchange reaction between solution and wall rock;
6. Changes in pH of the medium

Black smokers are hot fluids issuing from mid-oceanic ridge vents and on mixing with cold ocean water give rise to fluid rich in fine particles of black sulphide. The divergent margins or mid oceanic ridges and convergent plate boundaries have underwater volcanoes which produce hot springs known as hydrothermal vents. Black smoker vents (Fig. 12.7) are hydrothermal cones or chimneys that may reach a height of about 20m. Thus, black smokers are points of discharge of hot metalliferous solutions from the ocean floor. **White Smokers** are similar but precipitate metal oxides and sulphates. Black smokers and white smokers are natural laboratories to understand hydrothermal mineralisation.

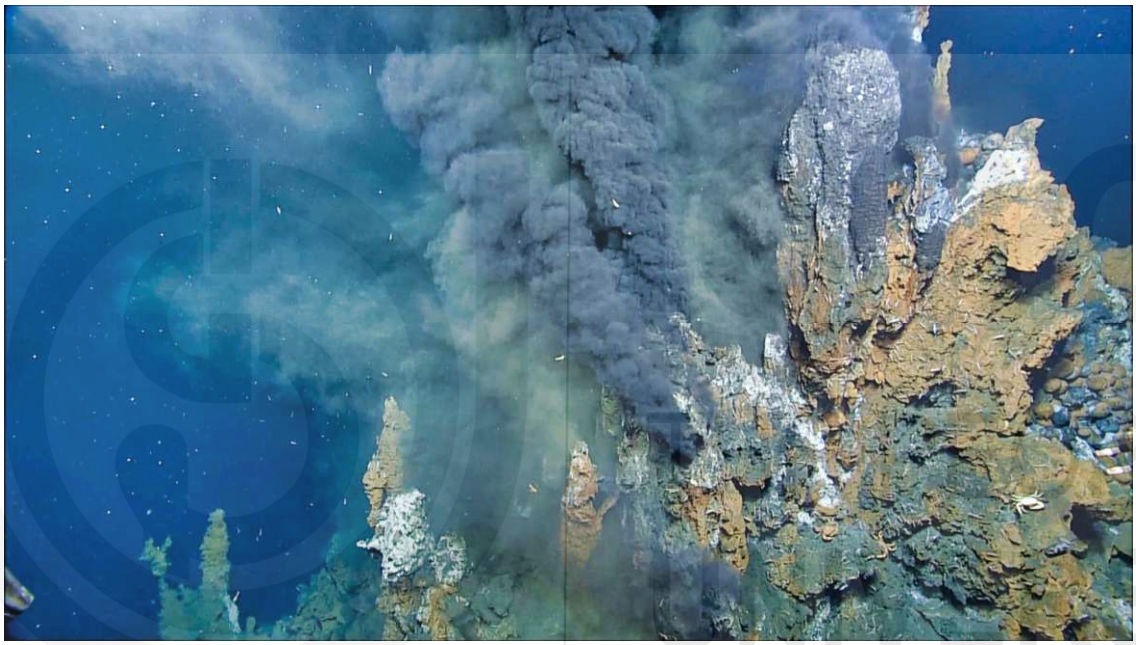


Fig 12.7: Black smokers emanating hot hydrothermal solution through vents. (Source: www.usgs.gov)

Watch the following video to more about black smokers and hydrothermal mineralisation.

- **Hydrothermal mineralisation**

  Link: http://egyankosh.ac.in//handle/123456789/53461

Wall Rock Alteration: A reaction of hydrothermal fluids with enclosing rocks, causes changes the mineralogy which is distinct from the adjacent lithology. Many ore deposits, particularly the epigenetic ones, may have a zone or zones of wall rock alteration of the host rock which are marked by colour, textural, mineralogical or chemical changes or any combination of these. The areal extent of the alteration can vary from few cm to a thick halo around an ore body. Few examples of wall rock alteration are given below:

- **Advanced argillic** - characterised by formation of clay minerals.
- **Potassic alteration** - characterised by secondary K feldspar and biotite.

- **Sericitisation**- characterised by the assemblage, quartz and sericite and pyrite.
- **Argillic** -characterised by kaolinite and montmorillonite.
- **Silicification** - characterised by quartz or chert.
- **Dolomitisation** - addition of magnesium to limestone to form dolomite.

The hydrothermal deposits have been classified into the following types based upon their mode of formation:

1) **Cavity-filling deposits**: They are found in the cavities or open spaces or fractures. The metallic minerals which are carried by the hydrothermal solution manage to get deposited in an epithermal condition. Cavities are of two types:
   - Original Cavities include pore spaces, crystal lattices, vesicles lava drain channel, cooling cracks and bedding plane
   - Induced cavities include volcanic pipes, shear zone cavities, collapse breccia and cavities due to folding.
2) **Metasomatic replacement deposits**: This type of deposits are formed when hydrothermal fluids react with the crustal material (minerals) thereby replacing it with the ore minerals which occur mostly under hypothermal conditions.

12.5.5 Contact Metamorphism and Contact Metasomatism

Magma, being a hot, fluid is charged with volatiles and is chemically very active. It starts reacting with the host rock which may either be an earlier formed igneous/metamorphic or a sedimentary rock. Contact metamorphism occurs as a result of a high geothermal gradient produced locally around intruding magma. Thus, magma on intrusion into a country rock will start not only baking the rocks at the contact, but there will be exchange relationship between the igneous constituents and the constituents of the intruded rock. This transfer of metallic constituents from the magma to the country rock will not only produce certain ore minerals, but shall also give rise to other characteristic mineralogy. Such types of deposits are also called as **contact metamorphic deposits**. They are usually restricted to relatively shallow depths in the Earth because it is only at shallow depths where there will be a large contrast in temperature between the intruding magma and the surrounding country rock.

Metamorphic deposits tend to be small in size, but are rich in grade. Small igneous intrusions such as dyke, sill, laccolith, lopolith and stocks have such deposits at their contacts. The contact metamorphic deposits are common in intrusive rocks of intermediate and felsic composition because they contain more water and volatiles compared to mafic intrusive rocks. Contact metamorphic deposits are formed in intruded rocks by fluids given off by intruding igneous magmas. The intruded rocks are modified or metamorphosed near the contact. This **zone of alteration** or **contact aureole** surrounding a body of igneous rock is formed by heat and volatiles given off as the magma crystallised. The changes are brought about in mineralogy, texture, or elemental and isotopic composition of the original enclosing (country or wall) rocks, which progressively increase closer to the igneous contact **(**Fig. 12.8). The **contact aureole** is the shell of metamorphosed or metasomatised rock enveloping the igneous body. Such changes may be small, consisting merely of baking, induration, or vitrification of the intruded rocks, or of recrystallisation of their constituent minerals. At many places, however, the changes are extensive, and the zone of altered rock may

extend many kilometers from the intruding mass. In general contact metamorphism is more profound along the contacts with intermediate or acidic rocks such as diorites, monzonites and granites than along the contacts of gabbros, diabases and pyroxenites.

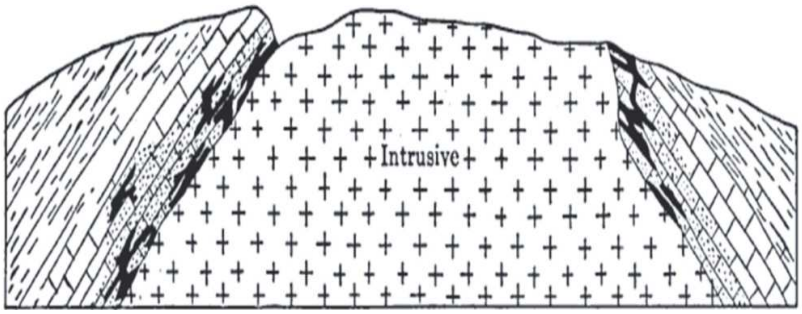


Fig. 12.8: Diagram showing relations of contact metamorphic deposits (black) to contact metamorphic zone (stippled) and to intrusive mass.

We have discussed about contact metamorphic process now we will read about contact metasomatic process. The alteration and replacement of the country rocks due to invasion of magmatic emanations may lead to the development of mineral deposits of economic importance **(**Fig. 12.9). The term **contact metasomatism** was introduced by Barrell in 1907 which refered to a process of chemical change in the composition of rocks adjacent to igneous intrusions, the change being brought about by migration of elements originating from the magma or the host. The country rocks are altered by chemical constituents of the invading intrusive magma forming new minerals under conditions of high temperature and pressure. The deposits are result in calcareous rocks and the temperature ranges from 400ºC to 1000ºC. The gangue minerals in these deposits comprise an assemblage of high temperature metamorphic minerals, called '**skarn**'. They are usually silicates of iron, magnesium, calcium and aluminium depending upon the nature of the country rock. Thus, deep seated batholiths masses occurring within pure or impure carbonate country rocks serve as most suitable locations, where the process of contact metasomatism can operate efficiently and lead to the development of mineral deposits. Thus, contact metasomatic deposits are formed in nature. Examples-cassiterite, magnetite, graphite, etc.

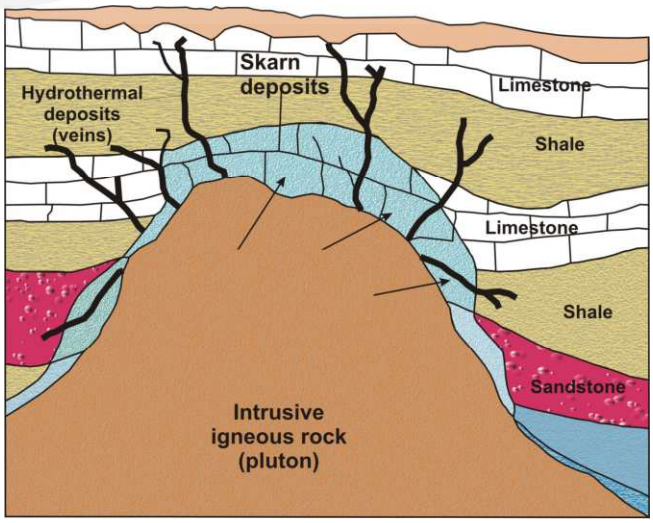


Fig. 12 9: Diagram showing the process of contact metasomatism and skarn deposits. Intrusive igneous body intruding the limestone and shale country rocks giving rise to contact metamorphic deposits. Subsequently emanations from the intruding magma result in formation of metasomatic (skarn) deposits.

Watch the following video to more about contact metasomatism and contact metamorphism.

- **Contact metasomatic and contact metamorphic deposits**

  Link: http://egyankosh.ac.in//handle/123456789/53458

12.5.6 Metamorphism

You will read about metamorphism in block 4 Metamorphic Petrology of BGYCT-135 course. Metamorphic processes intensely alter the pre-existing mineral deposits and form new ones. The chief agencies are heat, pressure, time and chemically active. The mineral deposits or rocks are the parent materials acted upon by metamorphic processes to form valuable mineral deposits. Thus, the metamorphic processes lead to form either a new mineral deposit or modify the existing mineral deposit. These processes may include deposits formed by the recrystallisation, reconstitution and mobilisation of the ore constituents. The metamorphic mobilisation means the movement and concentration of the ore constituents which is already present in the pre-existing rock, as a consequence of the metamorphism. All the processes of regional metamorphism, or contact metamorphism may give rise to the mineral deposits. Several kinds of non-metallic mineral deposits are formed as a result of regional metamorphism. Sedimentary rocks that had sufficient bituminous matter in them become the host rock to develop graphite due to regional metamorphism. Examples of ore deposits formed by metamorphism are asbestos, graphite, talc, soapstone and pyrophyllite. Gondite are manganese oxide found in deposit of Madhya Pradesh. It is one of the typical deposits developed during regional metamorphism. Khondalite, a metamorphic rock of Odisha is rich in garnet and sillimanite.

In the previous sections we have studied about the endogenous processes of ore formation. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 1

a) Differentiate between syngenetic and epigenetic type of deposits.

b) List the ore forming processes.

c) What is magmatic segregation?

d) List the types of hydrothermal deposits based on the temperature and pressure of formation.

12.6 EXOGENOUS PROCESSES OF ORE FORMATION

You have read about different endogenic processes in the previous sections. In this section you will learn about the exogenous processes like sedimentation, residual and mechanical concentration, evaporation etc.

The exogenous processes operate at the surface of the Earth for the formation of ore deposits. These involve processes that operate at low temperatures, low pressure, free movement of solutions, and free oxygen, water and CO_2 like weathering, erosion and sedimentation. Exogenous processes include sedimentary precipitation, residual concentration, supergene enrichment, bacteriogenic, evaporation and syn-sedimentary volcanogenic.

12.6.1 Sedimentation

Now let us discuss about the ores formed by the process of sedimentation. You will read in detail about the sedimentary rocks and process of sedimentation in course BGYCT-135. The formation of sedimentary rocks takes place by the process of sedimentation. Sedimentation also results in the deposition of valuable mineral deposits of iron, manganese, copper, phosphate, coal, oil shale, carbonates, cement rocks, clay, diatomaceous earth, magnesite and sulphur. The formation of sedimentary deposits involves:

- sufficient source of materials to be weathered and eroded;
- accumulation of weathered and eroded materials by mechanical and chemical processes;
- transportation of these materials to the site of accumulation; and
- deposition of transported materials in the sedimentary basin

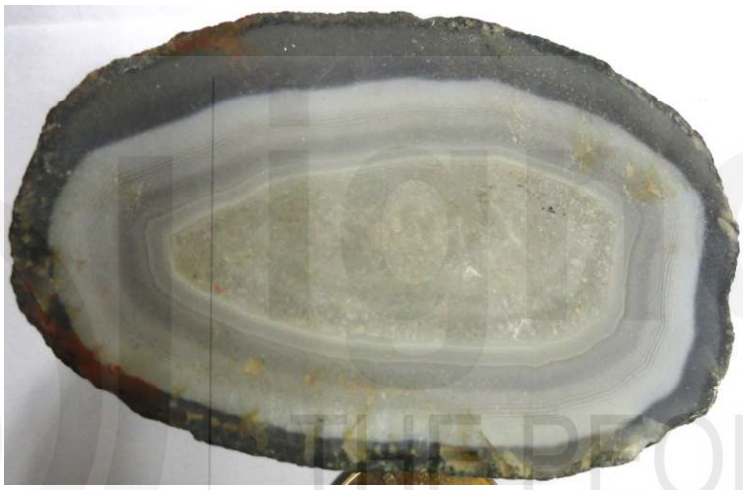
The processes of sedimentation include physical, chemical and biological components. The major subgroups of sediments and sedimentary rocks based on the mode of origin are:

- **Inorganic**-mechanical or clastic or terrigenous sediments, and
- **Organic**-chemical and biogenic sediments.

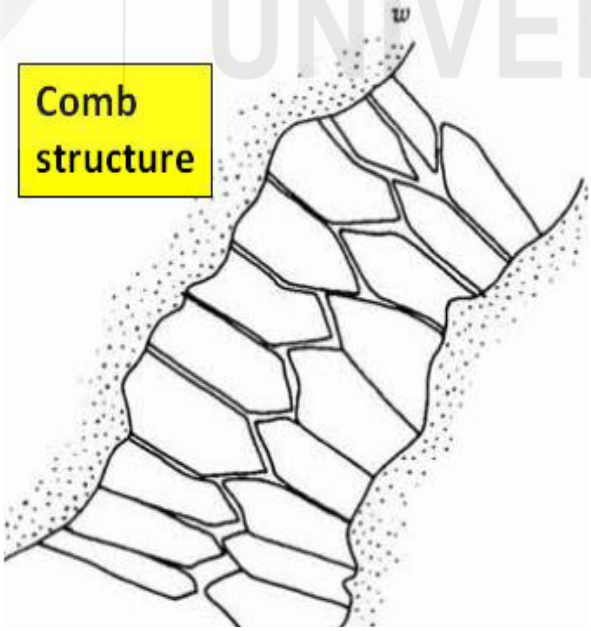
Inorganic or mechanical or clastic or terrigenous sediments/materials of economic importance are gravels, sand and certain clay. The source or provenance of the particles comprising these rocks is transported from distant places. The metallic deposits of this genetic group are called placers. **Placers** are mechanical formed enriched in heavy and chemically resistant native metals and minerals by flowing and agitating water. For example, gold, platinum, iron, tin, rutile, zircon, rare earth minerals, gems and other relatively insoluble materials. We will discuss about placers in the subsection 12.4.2 Residual and Mechanical Concentration.

Organic or chemical sediments are *insitu* deposits. This includes chemical precipitates and partly biogenic substances such as carbonate (limestone, magnesite, dolomite), evaporite (halite/rock salt, gypsum), banded iron formation, massive or oolitic limestone, etc. Some of the ore minerals get precipitated along with other chemical sediments due to favourable Eh-pH conditions of depositional environment. Majority of the world's Fe, Mn, and phosphate resources are the products of chemical sedimentation and are hosted in chemical sediments. Iron and manganese are the most important metals occurring as chemical precipitates in the sedimentary beds. Sedimentary deposits possess structures like bedding, cross bedding and other characteristic structures produced by sorting in water. They may even contain fossil remains. Banded structure is very common (Fig. 12.10a) but it is rarely symmetrical or crustified. Cavities or vugs are lined symmetrically with banded crusts (Fig. 12.10b). Banded Iron Formations (BIF) of peninsular India are represented by extensive thick sequences of Precambrian (Proterozoic) age. BIF are formed as a result of iron-rich waters reacting with oxygen released by algae during the early stages of the evolution of life. They are mostly laminated with fine grained hematitic layers which may be interbedded with jasper/quartzite/chert. The economically rich mineral deposits formed by organic processes can in cavities and fractures. They may be lined by comb structure showing growth of crystals outward (Fig. 12.10c). The chemical sediments may be oolitic, crystalline or amorphous (Fig. 12.10a).

(a)



(b)



(c)

Fig 12.10: Depositional structures in chemical sedimentary rocks: a) Banded Haematite Jasper is an iron ore of sedimentary origin, notice the bands in the photograph; b) Banded structure seen as cavity filling; and (c) Comb structure.

Mineral segregation takes place by the processes of weathering and erosion. Let us consider an example of granite which consists of minerals like quartz, potash feldspar and plagioclase, muscovite, biotite, magnetite and accessory minerals such as zircon, titanite, apatite and pyrite. During the process of weathering the rock with granitic composition tends to be converted to kaolin, and limonite; bauxite may also form. However, the resistant minerals like quartz, titanite, zircon and apatite escape weathering. During the process of chemical weathering the ground water which generally contains carbon dioxide dissolves and carries away alkalis and alkaline earths as carbonates or bicarbonates. The deposits of sedimentary origin may be found in association with all kinds of sedimentary rocks. The deposits of mechanical origin are likely to be found in conglomerates, sandstones and shales. Whereas deposits of chemical origin are commonly associated with limestones, shales or fine-grained sandstones.

12.6.2 Residual and Mechanical Concentration

In the subsection 12.6.1, we have read about ore deposits formed by the process of sedimentation. As we have read in unit 5 of course BGYCT-131 that the combined action of sharp temperature fluctuations, wind, water freezing in rock crevices and plant roots penetrating into the rock mass decomposes great blocks which gradually split into chunks and further reduced into smaller fragments. Apart from mechanical destruction the primary minerals are subjected to chemical alteration in which water plays a major role. The weathered products are transported by the multiple geological agents. Under the slow and relentless attack of multiple geological agents the weathering of rocks and enclosed mineral deposit undergo mechanical disintegration and chemical decomposition. The transported detritus gets deposited in aqueous medium and mechanical concentration.

The process of **residual concentration** can be explained as the concentration of ore present in the residue increases due to chemical weathering. The factors such as climate, local relief, presence of proper drainage etc. plays a vital role in the residual concentration. The amount of residue as *insitu* after weathering followed by transportation gives rise to ore deposits of economic importance. **Residual deposits** are formed by the removal of non-ore material or undesired constituents of rocks from **protore** (primary mineralised material too low in tenor to constitute ore) followed by their concentration by geological agents. Residual concentration of the valuable mineral deposit increases largely due to a decrease in volume affected removal of undesired material by surficial chemical weathering processes. The residues may continue to accumulate till their purity and volume make them of commercial importance. For example, the leaching of silica and alkalis from granite may leave behind a surface capping of hydrous aluminium oxides, i.e. bauxite.

We can define the **mechanical concentration** as the process of natural gravity separation of heavier minerals from lighter ones executed by the movement of water and wind by which the heavier minerals concentrated into deposits known as **placer deposits**. When the velocity of the flowing water slows down, the minerals with a higher density are deposited. Heavy minerals like gold, diamond, platinum and magnetite tend to get concentrated in areas where water current velocity is low. The lighter minerals like quartz or feldspar along with clays are carried away and get deposited to give rise sedimentary beds. Placer minerals get concentrated by flowing surface waters depositing high density minerals either in streams (Fig. 12.11) or along coastlines. The placer deposits are found in any area where current velocity is slow, such as:

- between the ripples (Fig. 12.11a);
- on or inside the meandering streams (Fig. 12.11b);
- behind rock bars (Fig. 12.11c); and
- in the holes on the bottom of a stream (Fig. 12.11d)

Placer forming activity has been operative throughout the geological history. The deposits are generally formed as loose sand/gravel. Gold is originally formed in hydrothermal veins. It gets eroded out of the veins and carried in streams where it is deposited in placer deposits. You must have heard of the famous California gold rush in 1849. It began when someone discovered rich placer deposits of gold in streams. According to the mode of origin placer deposits can be of following types:

- **Eluvial placers:** These are the accumulations of ore minerals which are at or still near the source. For example, diamond deposits in Chhattisgarh.
- **Colluvial placers:** These are ore minerals accumulated at the base of gentle slopes or hillsides mixed with any loose heterogenous and incoherent mass of rock fragments or soil.
- **Alluvial placers:** Alluvial deposits are clastic, detrital minerals transported by a stream and deposited at points along its flood plain.
- **Aeolian placers:** These are deposits which are result of erosion, transportation and deposition by the wind action. Aeolian placers diamonds are found in the Namibian desert of Africa.
- **Beach placers:** They are deposits of heavy minerals on contemporary or ancient beaches or along coast line. For example-monazite deposits at Kerala coast.
- **Fossil placers:** These deposits are also called palaeoplacers. South Africa is not only the world's largest and oldest palaeo placer deposit.

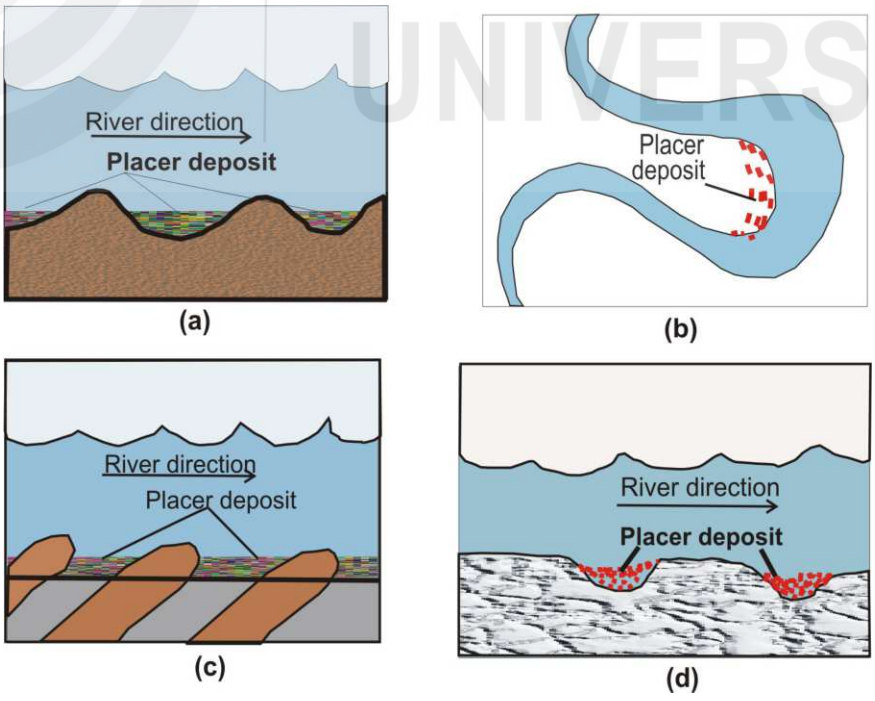


Fig. 12.11: Sites for placer deposits: a) Behind ripple marks; b) At the bend of meandering stream; c) Behind rock bars; and d) In holes present at the bottom of the river.

Let us learn the difference between residual concentration and mechanical concentration.

Residual concentration is the process of accumulation and concentration of valuable minerals when undesired constituents of rocks or mineral deposits are removed during weathering (dominantly chemical) processes. Whereas mechanical concentration is the separation of heavy from light minerals by means of moving water or wind as the result of natural gravity.

12.6.3 Oxidation and Supergene Enrichment

In the previous sections, we have read about the deposition of ore resulting due to magmatic and sedimentary processes. Sometimes the material left behind is sufficiently concentrated by weathering processes and ground water action to form residual deposits. Now in this section, we will learn about secondary or supergene enrichment where leaching of rocks/minerals takes place and precipitation occurs at the depth and produces higher concentrations.

Weathering of rocks and soil formation is considered as prerequisite for life on Earth, may affect the origin of many important ore deposits. You have read in detail about weathering in unit 5 of course BGYCT-131. Raw materials that are predominantly produced from supergene mineral deposits include a diverse range of metals and minerals such as iron, manganese, aluminium. The term ‘weathering’ integrates a number of processes that are caused by the interaction of Earth materials with the atmosphere and the energy flow from the Sun.

The definition from Evans (2013) states that supergene enrichment refers to leaching of valuable elements from the upper parts of mineral deposits and their precipitation at depth to produce higher concentrations. According to the definition from Guilbert and Park (1986), supergene enrichment occurs when the oxidising acids dissolve metal ions from the “protore” and redeposit it below the water table. This results in an oxidised zone on top (gossan), a supergene zone beneath and the hypogene (protore) zone below the supergene.

The principle of supergene ore deposit formation is the concentration of some dilute but valuable components of the primary rock. Let us learn about two basically different processes that may lead to concentration:

- In this process the valued component is enriched in a residuum, while much of the rock mass is dissolved and carried away.
- In this process the valued component is dissolved, transported, concentrated and re-precipitated.

Some of the ore deposits originate after long-distance transport dissolved in surface and groundwater. Supergene ore deposits form in regions where weathering is favoured by a hot humid climate that promotes the profuse growth of vegetation. Vegetation and organic matter affect supergene alteration by two mechanisms:

- it directly influences plants and soil water;
- it affects the abundance of organic acids and microbial activity that promotes dissolution of primary minerals.

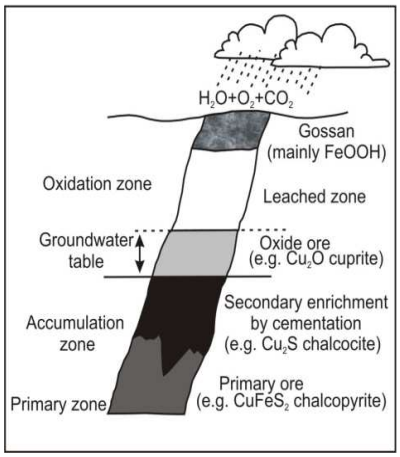
In this environment iron and aluminium are enriched in red, clayey and sandy soils. After a deposit has been formed, it undergoes upliftment and erosion. This may bring it

within reach of circulating ground water, which may leach some of the metals out of that section of the ore body above the water table. These dissolved metals may be redeposited in that part of the ore body lying beneath the water table and this can lead to a considerable enrichment in valued metals.

Surface waters percolating down the outcrops of sulphide ore-bodies oxidise many ore minerals and yield solvents that dissolve other minerals. Pyrite is quite common in sulphide deposits and it breaks down to produce insoluble iron hydroxides (limonite) and sulphuric acid. Copper, zinc and silver sulphides are soluble and thus the upper part of the sulphide ore body may be oxidised and generally leached of many of its valuable elements right down to the water table. This is called the **zone of oxidation**. The ferric hydroxide is left behind to form a residual deposit at the surface and this is known as a **gossan** or **iron hat** (Fig. 12.12). People involved in mineral exploration and prospecting, enthusiastically search for such features in the field. Gossan are signboards pointing towards what lies beneath the surface of the Earth. Gossan is Cornish word used to designate capping cellular mass of 'Limonite' and gangue minerals overlying sulphide deposits. Gossan word refers to heavy concentration of limonite material derived from massive sulphide minerals which have been leached and transported downwards.

Fig. 12.12: Field photograph of gossan or iron hat at Rajpur Dariba lead zinc mine. (Photo credit: Ganga Singh Bhartiya)

If the down trickling solutions penetrate the water table, their metallic content may be precipitated in the form of secondary sulphides to give rise to a **zone of secondary or supergene sulphide enrichment**. The lower, unaffected part of the deposit is called the **primary** or **hypogene zone** (Fig. 12.13). This zonal arrangement is characteristic of many mineral deposits that have undergone long continued weathering.



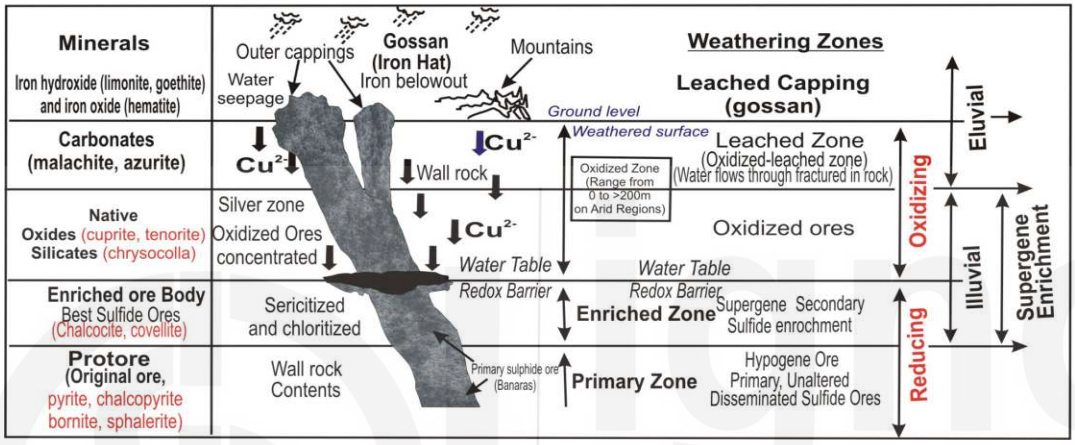


Fig. 12.13: Schematic profile of a deeply weathered copper sulphide ore deposit displaying the supergene 'secondary' zonation resulting from redistribution of elements. (Source: Pohl, 2011)

Oxidation and supergene sulphide enrichment is the process that generally works on sulphide deposits. In this process the metal bearing fluids produced by oxidation leaving percolate downwards behind 'hat' or gossan of iron oxides on leached part. While the fluids percolating downwards precipitate secondary oxide and carbonate minerals above the water table (oxidised zone). In some cases, metal bearing fluids penetrate below the water table (reducing environment) and get precipitated as sulphides with the help of sulphate-reducing bacteria. Thereby enriching the already present primary ore. Chalcocite, covellite, bornite are some of the most typical of supergene sulphide enriched minerals.

12.6.4 Evaporation

You have read about exogenous process of ore formation like oxidation and supergene enrichment and sedimentation. Now let us discuss about the evaporation process of formation of ores.

Evaporites are the rocks formed by the evaporation of water, for example halite (common salt),- gypsum and anhydrite. Most evaporites are of marine origin but terrestrially formed deposits by the process of evaporation are also of economic importance. Evaporation may take place on land or in the sea or shallow basins. The formation of evaporites may occur in the supra tidal zone (sabkhas) or within a restricted body of water, which may occupy a small or large basin (Fig. 12.14). The eroded material and salts are carried or transported by the rivers from land surfaces to the sea. When seawater evaporates, the salts precipitate and settle to the bottom. The

less soluble compounds are deposited first. Calcium sulfate comprising gypsum and anhydrite is deposited first. Next in the order of solubility is sodium chloride or halite compound. Modern examples of evaporate forming environments are well known. Thick and extensive Phanerozoic evaporitic deposits are also called as saline giants, of which no modern equivalents have been found.

Fig. 12.14: Formation of halite (NaCl) by the process of evaporation in Rann of Kutch.

12.6.5 Bacteriogenic Precipitation

Microbes including various kinds of bacteria, fungi, algae and protozoa are ubiquitous. Throughout the geological history microbes have played a significant role in breaking down rocks and minerals. Sedimentary deposits of iron, phosphorous and manganese have resulted due to active participation of bacterial activity. Bacteria plays role through production of H_2S and sulphuric acid. They are instrumental in developing oxidation and supergene enrichment sulphides. The bacteria play a significant role in the precipitation of manganese nodules, formation of coal and petroleum. Bacteria are operative upto 3000 meters below land surface and even in hotter conditions. Bacterial activity has also been reported from cold Arctic waters to hot springs.

The bacteriogenic precipitation processes are also closely associated with submarine exhalative volcanic process. The volcanic exhalative deposits serve as source of metals. These metals are resolved by the transport and escape of submarine hydrothermal fluids to the surface or near to the surface of the sea bottom. Then they spread laterally for some distance. Their precipitation takes place as concentric growth by bacteriogenic production of H_2S that reacts effectively and reduces metal solutions and form insoluble sulphides. The reduction of these sulphides to native sulphur is due to bacteriogenic precipitation processes. The sulphur reducing anaerobic bacteria such as *Desulfovibrio desulfuricans* and *Clostridium nigrificans* reduce SO_4^{2-} to H_2S. These deposits are epigenetic.

12.6.6 Syn-sedimentary Volcanogenic

Sedimentary volcanogenic or exhalative deposits also known as SedEx deposits. These ore deposits are interpreted to have been formed by release of ore-bearing hydrothermal fluids in the ocean. This results in the precipitation of stratiform ore deposits. Sedimentary exhalative deposits form where hydrothermal waters either blow

out as a plume or form a thick sequence of sediments into the bottom waters of sea and ocean. Several sulphide deposits are formed in submarine environment, where submarine volcanism occur. The deposits may be stratabound, lenticular bodies of massive pyritic mineralisation, contains chalcopyrite, sphalerite and galena in layered volcanic rocks. These are overlain by thin bedded siliceous and iron rich sedimentary or volcanic rocks.

In the previous section, we have studied exogenous processes of ore formation. Before going to the next section, spend 5 minutes to check how you are progressing.

SAQ 2

a) How are banded iron formation deposited?

b) What are residual deposits?

c) What are placer deposits?

d) List the types of placer deposits based on their origin.

e) What is gossan?

12.7 SUMMARY

In this unit, you have learnt about various types of ore deposits and their processes of formation. Now let us summarise about what we have learnt in this unit:

- Endogenous Processes include magmatic concentration, sublimation, pegmatite/pneumatolytic, hydrothermal and contact metamorphism and contact metosomatism and metamorphism.
- Exogenous Processes include deposits formed by sedimentation, residual and mechanical concentration, oxidation and supergene enrichment, evaporation, bacteriogenic precipitation and syn-sedimentary volcanogenic.
- Magmatic ore deposits also known as orthomagmatic ore deposits result from simple crystallisation and concentration by differentiation of intrusive igneous masses.
- Sublimation is a subordinate process of the formation of mineral deposits by compounds that are volatilised and subsequently re-deposited from vapour at lower temperature or pressure.
- Pegmatites are very coarse-grained igneous rocks formed during the final stages of magmatic crystallisation.
- Hot aqueous solutions that are responsible for the formation of hydrothermal ore deposits are termed as hydrothermal solutions.
- Contact metamorphic deposits are formed in intruded rocks by fluids given off by intruding igneous magmas. Metamorphic processes intensely alter the pre-existing mineral deposits in the presence of heat, pressure, time and chemically active to form valuable mineral deposits.

- Organic or chemical sediments are *insitu* deposits include chemical precipitates and partly biogenic substances such as carbonates, evaporite, banded iron formation, massive or oolitic limestone, etc.
- The process of residual concentration can be explained as the increase in concentration of ore present *insitu* after weathering.
- Mechanical concentration are the process of natural gravity separation of heavier minerals from lighter due to movement of water, air into deposits known as placer deposits.
- Supergene sulphide enrichment is the natural upgrading of buried sulphide deposits by the secondary or subsequent deposition of metals.
- Evaporites are mineral deposits formed by the evaporation of water in marine origin but terrestrially formed deposits are also of economic importance.
- Microorganisms especially bacteria are involved precipitation of ore deposits like manganese nodules. The production of hydrogen sulphide by bacterial activity plays a great role in precipitation of rich mineral deposits.

12.8 ACTIVITY

- Make a list of endogenous and exogenous ore deposits
- Find out the places and enlist the ore deposits that are found in your state. You can take help of the websites of Geological Survey of India, Indian Bureau of Mines and Directorate of Geology and Mining of your state.

12.9 TERMINAL QUESTIONS

1. Differentiate early and late magmatic concentration processes. Explain process of sublimation deposits.
2. Explain the formation of contact metasomatic and contact metamorphic deposits.
3. What are hydrothermal fluids? Discuss the formation of hydrothermal ore deposits.
4. Discuss the formation of placer by mechanical concentration.

Audio/video material based questions

- What are syngenetic ore deposits?
- Give examples of ore deposits formed by early magmatic dissemination and segregation.
- What is residual liquid injection?
- What are disseminated type of deposits?
- What are hydrothermal vents?
- How are black smokers formed?
- Differentiate between contact metasomatism and contact metamorphism.

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12.12 ANSWERS

Self Assessment Questions

1 a) Syngenetic deposit refers to ore deposits that form at the same time as their host rocks. Epigenetic deposits are formed later than the rocks that enclose them.

b) Endogenous Processes: Magmatic concentration, sublimation, pegmatite/ pneumatolytic deposits, hydrothermal deposits, contact metamorphism and metasomatism.

c) Exogenous Processes: Sedimentation, residual and mechanical concentration, oxidation and supergene enrichment, evaporation, bacteriogenic precipitation and syn-sedimentary volcanogenic.

d) Magmatic segregation is a process by which one or more minerals become locally concentrated or segregated during the cooling and crystallisation of magma resulting in magmatic cumulate.

e) Hypothermal, mesothermal, epithermal, telethermal and xenothermal deposits.

2 a) Banded Iron Formation are formed as a result of iron-rich waters reacting with oxygen released by algae in the early stages of the evolution of life. They are mostly laminated with fine grained hematitic layers may be interbanded with jasper/quartzite/chert.

b) Residual deposits are formed by the removal of non-ore material or undesired constituents of rocks from protore. Residual concentration of the valuable mineral deposit increases in their purity and volume to make them commercial important.

c) Mechanical concentration is the process by which gravity separation of heavier minerals from lighter ones takes place by the movement of water or air to form deposits known as placer deposits.

d) Eluvial placers, colluvial placers, alluvial placers, aeolian placers, beach placers, fossil placers.

e) Gossan is Cornish word used to designate capping cellular mass of 'Limonite' and gangue minerals overlying sulphide deposits. Gossan word refers to heavy concentration of limonite material derived from massive sulphide minerals which have been leached and transported downwards.

Terminal Questions

1. Please refer to subsection 12.5.1 and 12.5.2
2. Please refer to subsection 12.5.5.
3. Please refer to subsection 12.5.4.
4. Please refer to subsection 12.6.2.

UNIT 13

METALLIC MINERALS

Structure

13.1 INTRODUCTION

The global demand for minerals has increased steadily since the industrial revolution and exponentially in the latter half of the 20th century. The increasing global population and prosperity of societies is bound to keep this demand rising. A significant part of global economy is clearly dependant on mineral production which is the backbone of modern industrialisation. In unit 12, we have learnt about ore forming processes which are very complex in nature. We have also learnt that ore deposits comprise ore and gangue minerals. These two differ in process of

formation, mineralogy, texture, content and other features. In the previous unit we have also studied that ore forming processes can be grouped in two broad categories namely endogenous and exogenous processes. Now in this unit, we will discuss in detail about metallic mineral deposits in context to their chief ores, process of formation and distribution in India. Metals like iron, manganese, nickel and cobalt come under the category of **ferrous metals**. Copper, lead and zinc are grouped as **base metals**. Aluminium and magnesium are known as **light metals** and metals like gold and silver come under the category of **precious metals**.

Expected Learning Outcomes

After reading this unit, you should be able to:

- discuss the ores of ferrous metals like iron and manganese, their processes of formation, distribution in India and uses;
- describe the ores of base metals like copper, lead and zinc, their processes of formation, distribution in India and uses;
- identify the ores of precious metals like gold, their processes of formation, distribution in India and uses;
- learn about the ores of light metals like aluminium, processes of formation; distribution in India and uses; and
- know about the radioactive metals like uranium and thorium.

13.2 IRON

We have learnt above that metals like iron, manganese, nickel and cobalt are grouped as ferrous metals. We will discuss about iron and manganese in this unit.

We all know that iron is the most vital metal in human use. Iron accounts for more than 95% of all metals used by the modern society. The industrial growth of a country apart of other criteria is measured by the amount of iron consumption and steel production. Iron constitutes 5.05% of the Earth's crust and holds third position in abundance after silicon (28.2%) and aluminium (8.2%). It is rarely found in native conditions except in meteorites and some eruptive rocks. Iron is found in rocks mostly as silicates and oxides. The mineral containing iron must be mineable at profit in order to be called an Iron Ore.

13.2.1 Chief Ores

You can classify iron ores (Fig. 13.1) into four categories based on the chemical composition:

- Oxides (magnetite or hematite)
- Carbonates (siderite)
- Sulphides (Fe sulphide-FeS_2)
- Silicates (Fe-olivine which is fayalite)

The chief ores of iron are its oxides, sulphides and carbonates as listed below in Table 13.1.

Table 13.1: Chief ores of iron.

Category	Ore Mineral	Composition	Tenor (Fe%)	Physical properties
Oxides	Hematite	Fe_2O_3	74	Colour-steel grey to red Streak -cherry red Sp. Gr.- 5.17
	Magnetite	Fe_3O_4	70	Colour-black or brown black. Streak-black Sp. Gr. -5.17
	Goethite	FeOOH	68.5	Colour-reddish to yellowish brown Streak-yellowish brown Sp. Gr.-3.3-4.3
	Limonite	$(FeO(OH)\cdot n(H_2O)$	55	Colour-yellowish brown to brown to black Streak-yellowish brown Sp. Gr. -2.7-4.3 (varies with impurities)
Sulphide	Pyrite	FeS_2	46.8	Colour-brass yellow Streak- greenish to brownish black Sp. Gr.- 4.9 to 5.2.
Carbonate	Siderite	$FeCO_3$	48.3	Colour- yellowish brown, brown, grey, yellowish grey, greenish grey Streak- ash grey to brown Sp.Gr. -3.96

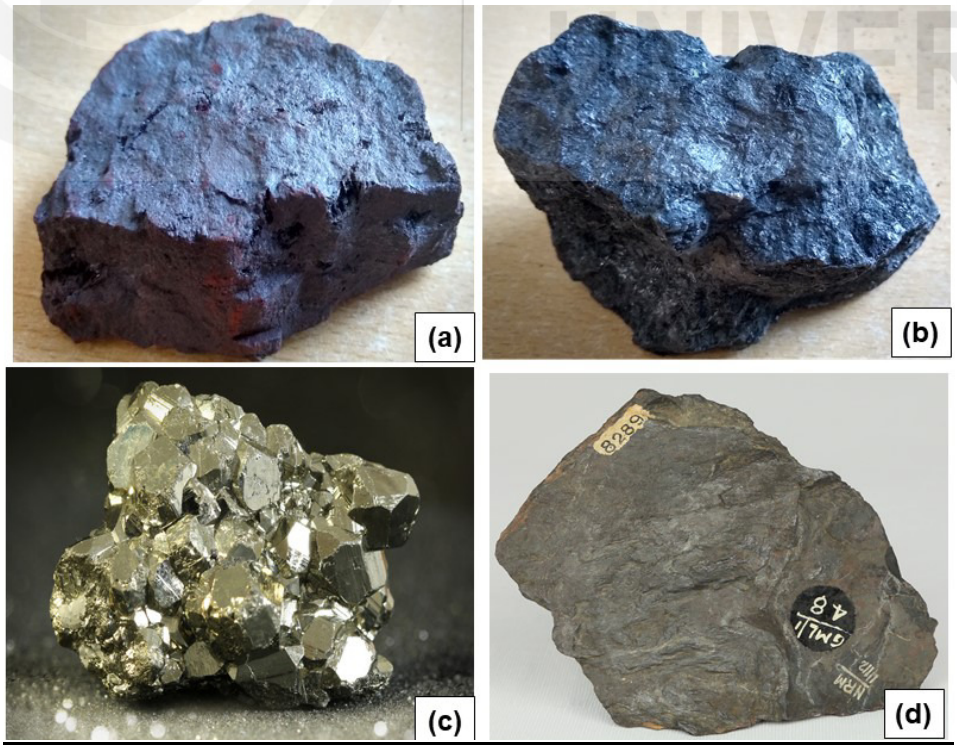


Fig. 13.1: Important iron ores in hand specimens: a) Hematite; b) Magnetite; c) Pyrite; and d) Ilmenite. (Source: www.gsi.in for ilmenite)

13.2.2 Processes of Formation

Let us discuss the process of formation of iron ores.

The ores of iron can be of magmatic, sedimentary and metamorphic origin occurring in different geological settings. Magnetite also occurs as magmatic segregation associated with layered mafic-ultramafic intrusions. Magnetite and micaceous hematite are produced by contact metamorphism, as in Iron springs, Utah, USA. Iron ores of sedimentary origin are the largest resource of the metal and are exploited extensively all over the world. Lateritic iron ores are commonly found in tropical humid regions over ferruginous bed rocks.

Two major groups of iron rich sedimentary rocks are commonly recognised (James, 1966):

1. **Banded Iron Formations (BIF)**: They are represented by extensive thick sequences of Precambrian age. They are typically laminated with fine grained hematitic layers interbedded with chert/jasper/quartzite.
2. **Ironstones**: These are poorly banded, non-cherty and oolitic ores, represented by hematite and goethite and are of Phanerozoic age.

Let us discuss in brief about the processes of formation of iron ores found in India.

- **Metamorphic banded deposits**: The major iron ore deposits of India fall within this group. Indian iron ore deposits of Jharkhand Odhisa belt, Bailadila (MP) and those of Karnataka are typical examples. Example- banded magnetite quartzite.
- **Continental sedimentary deposits**: These were formed in fresh water (fluvial or lagoonal) or under brackish swamp (lacustrine) conditions. Ironstones of Raniganj Coalfields are typical examples of this type of deposit.
- **Marine sedimentary deposits, detrital, placer and mixed type**: The magnetite deposits of coastal regions of Kerala are associated with ilmenite and heavy mineral sands.
- **Volcano sedimentary deposits**: These deposits are related to volcanic rocks of subduction zone tectonic setting. They occur as significant minor pockets in the Ladakh Himalaya.
- **Liquid magmatic deposits**: Iron ore deposits are formed by gravitational differentiation during early crystallisation of mafic plutonic rocks. For example- Mayurbhanj District of Odisha.
- **Intrusive magmatic deposits**: They are related to alkaline rocks of Precambrian shields. For example-apatite-magnetite rocks of Singhbhum region.
- **Contact metasomatic deposits**: These are found at the contact aureoles of granitoid intrusions within the limestone. Examples are magnetite deposits of Vishakhapatnam District of Andhra Pradesh and Palamau District of Jharkhand.

Watch the following video to more about the formation of iron ore deposit.

- **Early magmatic deposits**

  Link: http://egyankosh.ac.in//handle/123456789/53456

13.2.3 Distribution in India

We will study the distribution of Indian iron ore deposits based on their origin and mineralisation into the following four groups (Deb and Kaur, 2004):

First group comprises major iron ore deposits of the country, associated with BIF of Precambrian age. These iron ore deposits grouped into two (Radhakrishna et al., 1986):

- They were deposited > 3000 Ma ago and occur within complexly folded BIFs in parts of Andhra Pradesh, southern Karnataka, Kerala and Tamil Nadu, and
- They were formed during the period 2900 to 2600 Ma ago and restricted to the Archean schist/greenstone belts in Odisha, Jharkhand, Madhya Pradesh, Goa, Maharashtra and Karnataka.

Iron ore Formations are exposed in three principal belts around the Singhbhum granite massif in south Jharkhand and northern Odisha (Fig. 13.2). They are:

- Gorumahisani and Badampahar hills of Mayurbhanj District of Odisha;
- Jamda-Koira valley deposits to the west; and
- Sukinda valley, Tumka-Daiteri and Malayagiri deposits in the south

The deposits in these regions provide the iron ore to the SAIL steel plants at Rourkela, Bokaro, Durgapur and Kulti, besides TISCO.

Second group comprises the apatite-magnetite ores of the Singhbhum shear zone, in Jharkhand and the titaniferous, vanadiferous magnetite deposits associated with intrusive mafic plutons in Mayurbhanj District of Odisha (Fig. 13.2).

Third group consists of sedimentary iron-ores of limonitic or sideritic composition and occur in Raniganj and Jharia coalfields of West Bengal and Jharkhand respectively and Tertiary formations of Assam (Fig. 13.2).

Fourth group consists of iron ore derived from the residual concentration of iron-bearing minerals in igneous, metamorphic and sedimentary rocks. These lateritic iron ores found extensively on the Eastern and Western Ghats (Fig. 13.2).

13.3.4 Uses

Iron found its industrial use first time in 800 BC which marks the commencement of Iron Age. With steel gaining its importance in the 19th century the Iron Age culminated in Steel age. The iron ore is basically used for the extraction of iron metal in the form of cast iron, wrought iron, steel and iron alloys which have their own particular uses. The iron metal finds its use both in home and outside. It has a major role in building construction, farm tools, machines, rails, automobiles, ships etc. besides domestic utensils. The other use of iron ore is coal washery. It is also used in cement industry to make up the proportion of iron in the raw material. Iron ore is mainly utilised for making pig iron, sponge iron and steel.

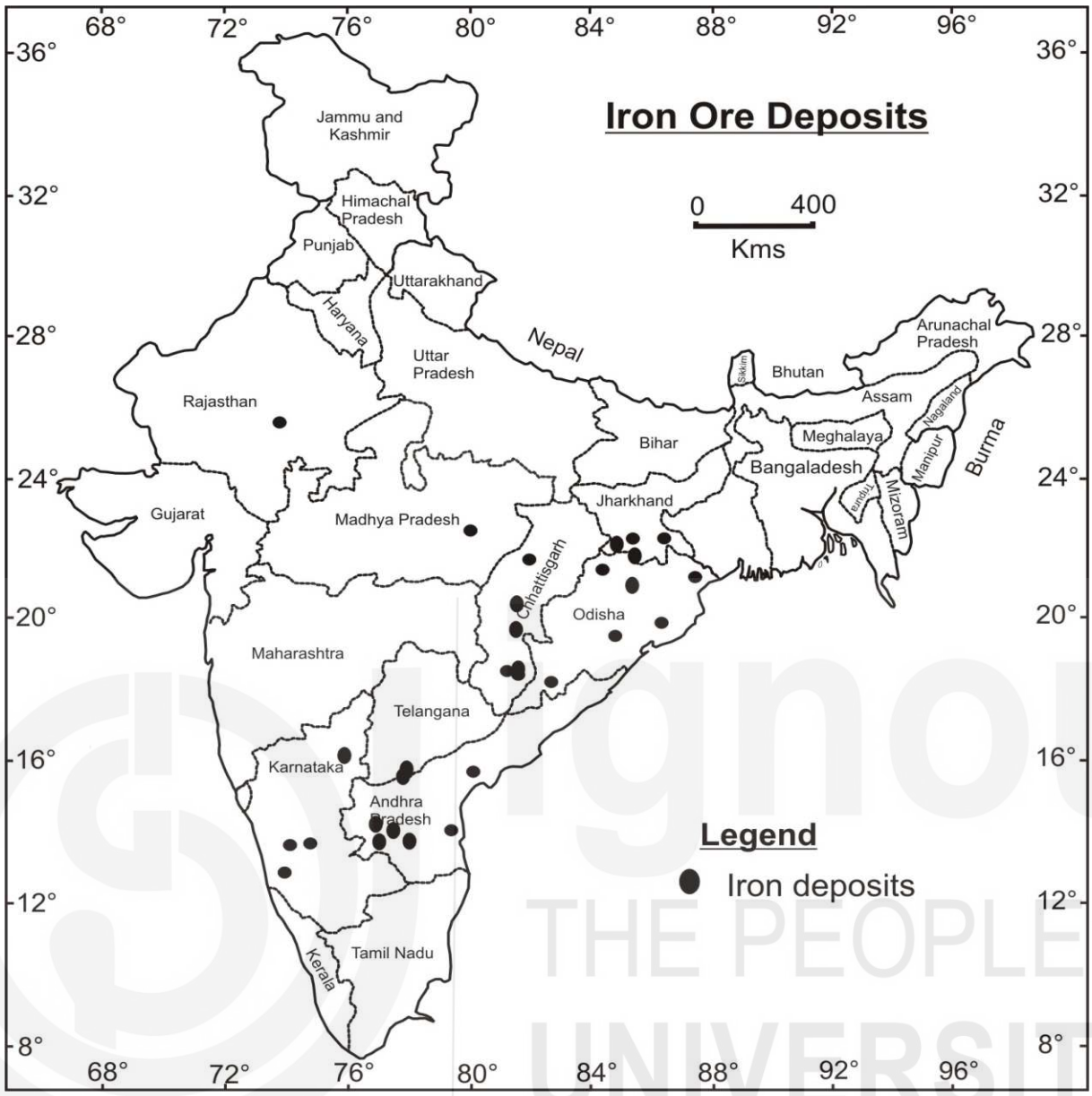


Fig. 13.2: Map of India showing spatial distribution of iron ore deposits. (Source: Modified after Prasad, 2011)

13.3 MANGANESE

Now let us discuss about another ferrous metal like manganese (Mn). In comparison to iron manganese is much less abundant (0.095%) in the Earth's crust. Hence, manganese deposits are not as common or abundant as the iron ore deposits. Manganese is a metal crucially required for steel production. The total reserves of manganese in India are estimated to be 93,000,000 metric tons.

13.3.1 Chief Ores

Manganese is widely distributed in Earth's crust in the form of oxides, carbonates and silicates. Manganese does not occur in the native state in nature, but it may be produced by electrolysis or by reduction of its oxides. It is pinkish grey metal very hard and brittle melting at about 1260oC. Manganese can occur in nature as oxide, carbonate and silicate. Pyrolusite and psilomelane are common manganese ore (Fig. 13.3).

Table 13.2: Chief ores of manganese.

Category	Ore Mineral	Composition	Tenor (Mn%)	Physical properties
Oxides	Pyrolusite	MnO_2	63.2	Colour- dark grey to black Streak-Bluish black to black Hardness-2-2.5; Sp. Gr.-4.8
	Psilomelane	$(Ba,H_2O)_2Mn_5O_{10}$	45-60	Colour-iron black Streak-brownish black Hardness-5-6; Sp gr.-3.7 to 4.7.
Carbonate	Rhodochrosite	$MnCO_3$	46.86	Colour-pink Streak-white Hardness-3.5-4.5; Sp. Gr. 3.45 to 3.6.
Silicate	Rhodonite	$MnSiO_3$	38.29	Colour-red, pink, orange red and brownish Streak-colourless Hardness-5.5-6.5; Sp. Gr. 5.5-6.5

(a) **(b)**

Fig. 13.3: Manganese ores: a) psilomelane in botryoidal form; and b) pyrolusite in massive form.

13.3.2 Processes of Formation

Manganese occurs in deposits of diverse genetic types occur in a large span of terrestrial geological record. Hydrothermal activity, sedimentation processes, continental weathering are the processes responsible for forming manganese deposits (Roy, 1981). Most of the existing demand for manganese is met from the sedimentary and residual deposits. Manganese also occurs as ferromanganese

nodules (Fig. 13.4) in the deep ocean floor of Indian Ocean. The deep-sea nodules form future resource of manganese and some other important metals such as cobalt, nickel, copper etc. The bedded deposits are formed by the metamorphism of manganiferous sediments. The lateritic deposits have resulted from the surface alteration of manganiferous rocks of Dharwar Group. The Indian deposits are either of bedded (both syngenetic and supergene) or lateritic type. Of the bedded type, the most important manganese ore deposits occur in form of sedimentary, stratified metamorphic deposit within the Gondite and Kodurite rocks of Proterozoic age.

Fig. 13.4: Ferromanganese nodules. (Source: www.usgs.gov)

13.3.3 Distribution in India

Indian manganese ore deposits occur mainly as metamorphosed bedded sedimentary deposits associated with Gondite Series of Madhya Pradesh in Balaghat, Chhindwara and Jhabua Districts, Maharashtra in Bhandara and Nagpur Districts, Gujarat in Panchmahal District, Odisha in Sundergarh District and with Kodurite Series of Odisha in Ganjam and Koraput Districts and Andhra Pradesh in Srikakulam and Visakhapatnam Districts. Manganese ore production in Indian states for the year 2016-17 is shown in Fig. 13.5. The distribution of manganese ore in India is shown in Fig. 13.6.

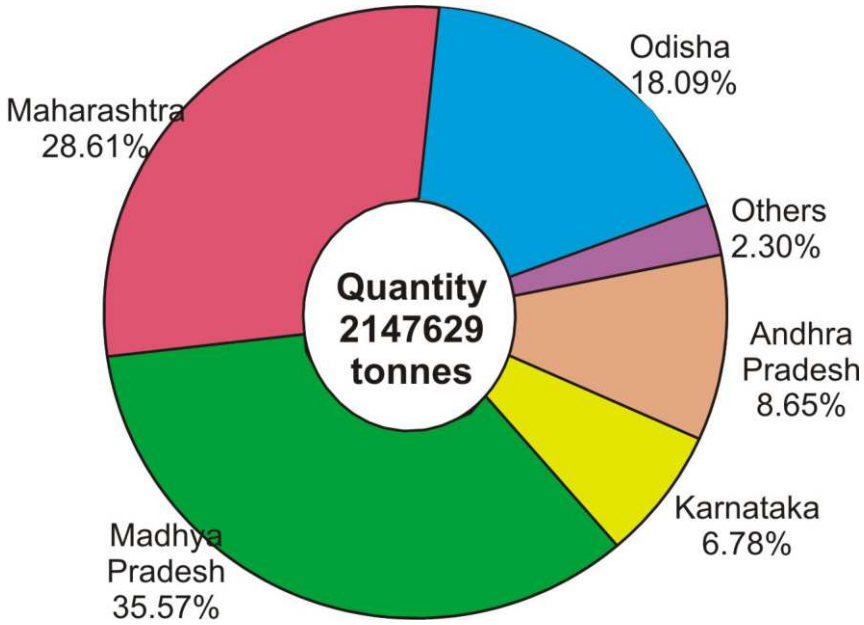


Fig. 13.5: Manganese ore production in Indian states for the year 2016-17. (Source: Indian Bureau of Mines in 2018)

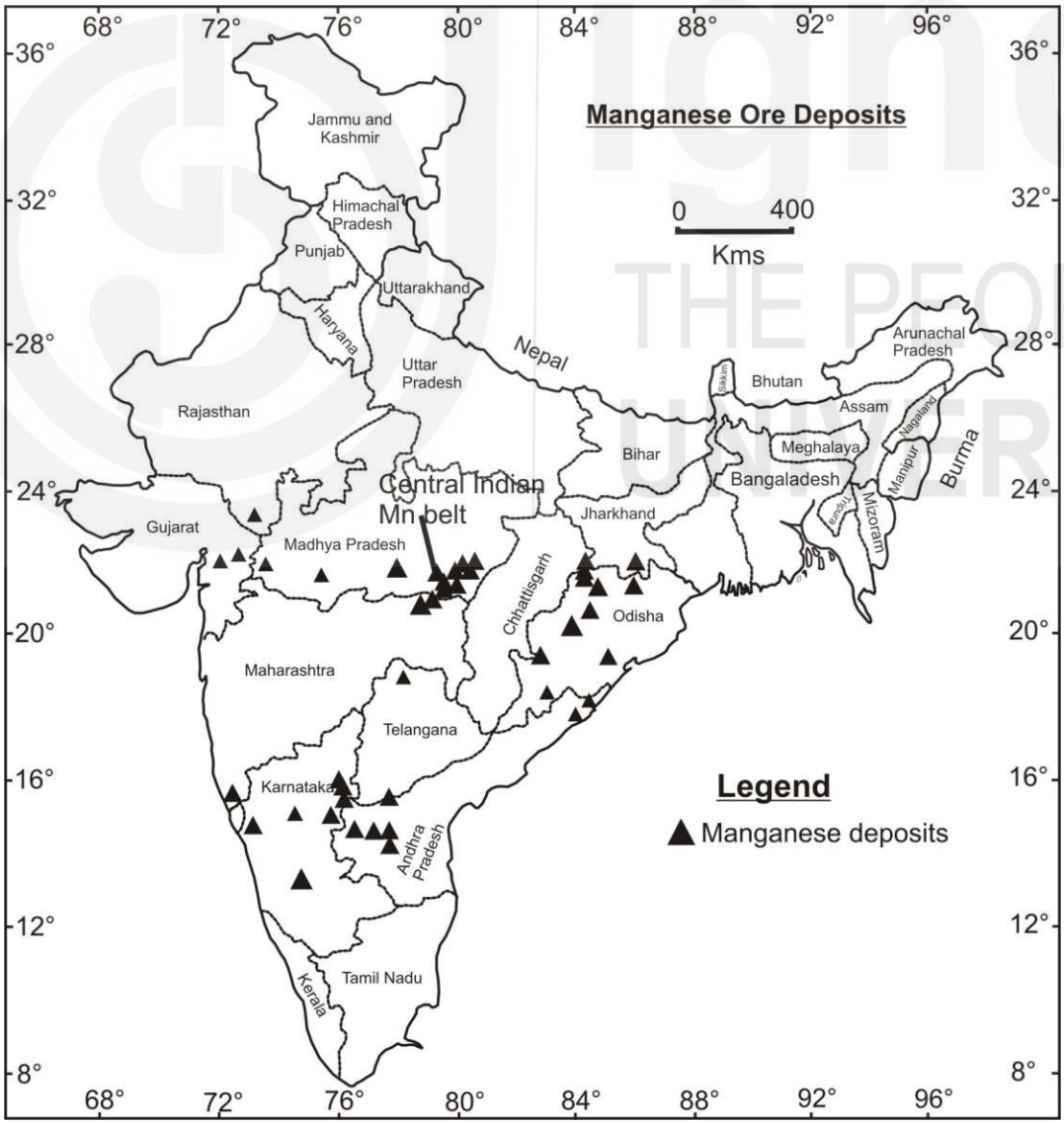


Fig. 13.7: Map of India showing spatial distribution of manganese ore deposits. (Source: Modified after Prasad, 2011)

13.3.4 Uses

The manganese ore attracted the attention of industry for the first time as raw materials for medicines and paints at the end of the 18th century. With the growth of steel industry and the introduction of new techniques, the demand of manganese ore increased and current world production exceeds 26.4 million tonnes. Mn Ore is an important raw material in iron and steel metallurgy where it is used in the form of ferromanganese. It improves the strength, toughness, hardness and workability of the steel. Mn ore is also used for manufacturing dry cell batteries and chemicals. Manganese dioxide is used for manufacturing glass.

13.4 COPPER

We have learnt about ferrous minerals like iron and manganese. Now in this section and the next section we will discuss about ore, processes of formation and distribution of non-ferrous or base metals like copper, lead and zinc. The base metals tarnish, corrode or oxidise on exposure to air, moisture or heat. Copper is the most useful base metal. Due to its electrical conductivity and ductility, it is widely used in the manufacture of wires, plates and rods for use in electrical industry and domestic utility.

13.4.1 Chief Ores

The copper ores (Fig. 13.8 and 13.10) are divided into four groups based on chemical composition: native metal, sulphides, oxides and complexes. The native copper occur as an individual mineral with 100% Cu is commonly found in oxidised zones. The chief ores of copper along with their chemical composition, copper percentage and physical properties are mentioned below in the Table 13.3.

Table 13.3: Chief ores of copper. (Source: Alexander, 2009)

Category	Ore mineral	Composition	Tenor (Cu %)	Physical Properties
Sulphides	Chalocopyrite	$CuFeS_2$	34.5	Colour-brassy yellow Streak- greenish black Hardness: 3.5-4; Sp. Gr.-4.2
	Bornite (peacock ore)	Cu_5FeS_4	63.3	Colour-reddish brown or brownish red on fresh surface. Iridescent blue and black on tarnished surface Streak-dark grey to black Hardness: 3; Sp. Gr.-5.05
	Chalcocite	Cu_2S	79.8	Colour- blue black, grey, black, steel grey Streak- greyish black Hardness: 2.5; Sp. Gr.- 5.65
	Covellite	CuS	66.4	Colour-Indigo blue Streak- black grey Hardness: 1.5-2;Sp. Gr.- 4.6 - 4.76
Oxides	Cuprite	Cu_2O	88.8	Colour- shades of red Streak- shining brownish Hardness: 3.5-4; Sp. Gr.- 6.1

	Tenorite	CuO	79.8	Colour- grey, black Streak- black Hardness: 3-4; Sp. Gr.- 6.25
Carbonate	Malachite	$CuCO_3$. $Cu(OH)_2$	57.3	Colour-bright green encrustations Streak- light green Hardness: 3.5-4; Sp. Gr.- 3.6 - 4.05
	Azurite	$Cu_3(CO_3)_2(OH)_2$	55.1	Colour- azure blue, blue, light & dark Streak- light blue Hardness: 2-4; Sp. Gr.- 3.83
Silicate	Chrysocolla	$CuSiO_3.2H_2O$	36	Colour-bluish green or sky blue Streak- light green Hardness: 3.5-4; Sp. Gr.- 2.15
Element	Native Copper	Cu	100	Colour- copper red on a fresh surface, dull brown on tarnished surface Streak- Metallic copper red Hardness: 2.5-3; Sp. Gr.- 8.9

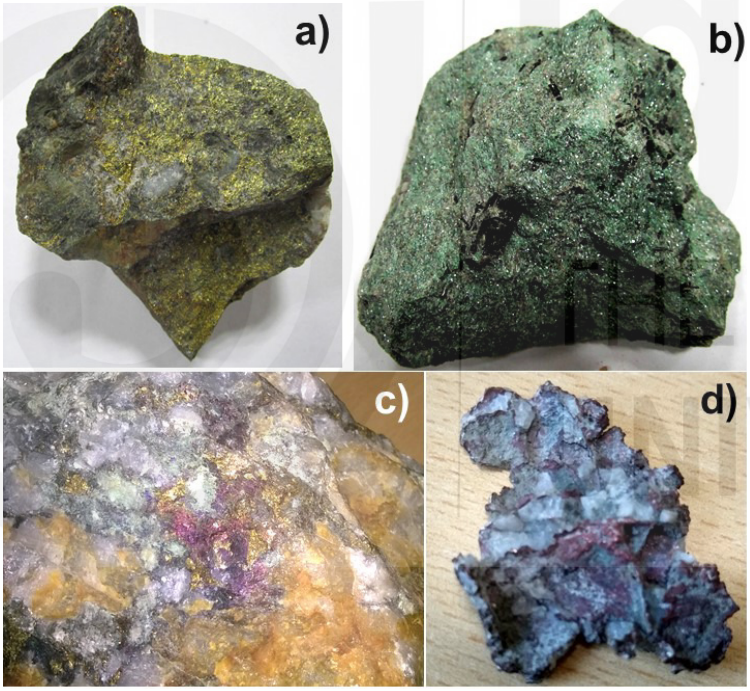


Fig. 13.8: Photographs of copper ores in hand specimen: a) Chalcopyrite; b) Malachite; c) Cuprite (reddish brown copper red colour) associated with chalcopyrite (golden yellow); and d) Native copper.

13.4.2 Processes of Formation

Copper deposits have originated by diverse processes like magmatic segregations, hydrothermal activity, submarine exhalations, bacteriogenic precipitation and oxidation and supergene enrichment. Copper ores also occur in clastic sedimentary rocks. Copper may also be associated with zinc, lead, gold and silver minerals. Porphyry copper deposits are closely associated with intrusions of monzonite, quartz monzonite or quartz porphyry. Most copper deposits are the result of oxidation and some supergene enrichment with rich grades at the upper levels just below the water table. Contact metasomatism also accounts for some deposits of copper in

carbonate rocks. Copper occurs as magmatic segregations and contact metamorphic deposits. In India copper lodes occur mostly in veins, stringers, patches, disseminated forms, fracture and cleavage fillings, associated with different rocks. Other metals, such as lead, zinc, gold, silver, platinum, palladium, bismuth, etc are associated with copper ores.

Watch the following video to more about the copper deposit formed by contact metasomatism.

- **Contact metasomatic and contact metamorphic deposits**

  Link: http://egyankosh.ac.in//handle/123456789/53458

13.4.3 Distribution in India

The major copper deposits in India are located in the states of Jharkhand, Rajasthan, Madhya Pradesh and Karnataka. Minor occurrences of copper in polymetallic association are found in Sikkim, Maharashtra and Andhra Pradesh (Fig. 13.9).

The Singhbhum Thrust Belt is a 128 km long arcuate structural zone in the southern part of Jharkhand state. It hosts several mineral occurrences of economic importance. It is perhaps the oldest copper mining region in the country where mining began around 2000 BC. This belt hosts several copper, uranium and apatite-magnetite deposits.

Khetri copper belt in Jhunjhunu District of Rajasthan is about 80 Km long. The mineralisation of chalcopyrite, pyrrhotite and pyrite has taken place along favourable structural zone like shear zone and cleavage plane.

Hindustan Copper Ltd's Malanjkhand mine is the biggest open pit base metal mine in India located in Balaghat District of Madhya Pradesh state. Lode-type copper mineralisation occurs within calc-alkaline tonalite-granodiorite plutonic rocks. Chalcopyrite is main ore mineral (Fig. 13.10). In Karnataka, Chitradurga Copper Company mined a small pyritic copper deposit within Chitradurga Group volcanic rocks at Ingaldhal, a few km away from the town of Chitradurga.

13.4.4 Uses

Copper is one the most essential of all non ferrous metals being used by man since before the Bronze Age. Various uses due to specific properties of copper are given below in the Table 13.4.

Table 13.4: Summary of uses and specific properties of copper.

SN	Uses	Properties
1.	Ornaments, vessels	Ductile, malleable, soft metal, can be easily shaped
2.	Electrical industry as conductors, windings and other components of chemical machines	High electrical conductivity
3.	Steam engine automobiles and other machines	Unique properties not found in other metals
4.	Used in alloys like bronze, duralumin, gun metal	Readily mixes with certain metals
5.	Chloride is used as disinfectant and in chemical operations; sulphate is employed in printing and dyeing textiles.	Properties of salts of copper

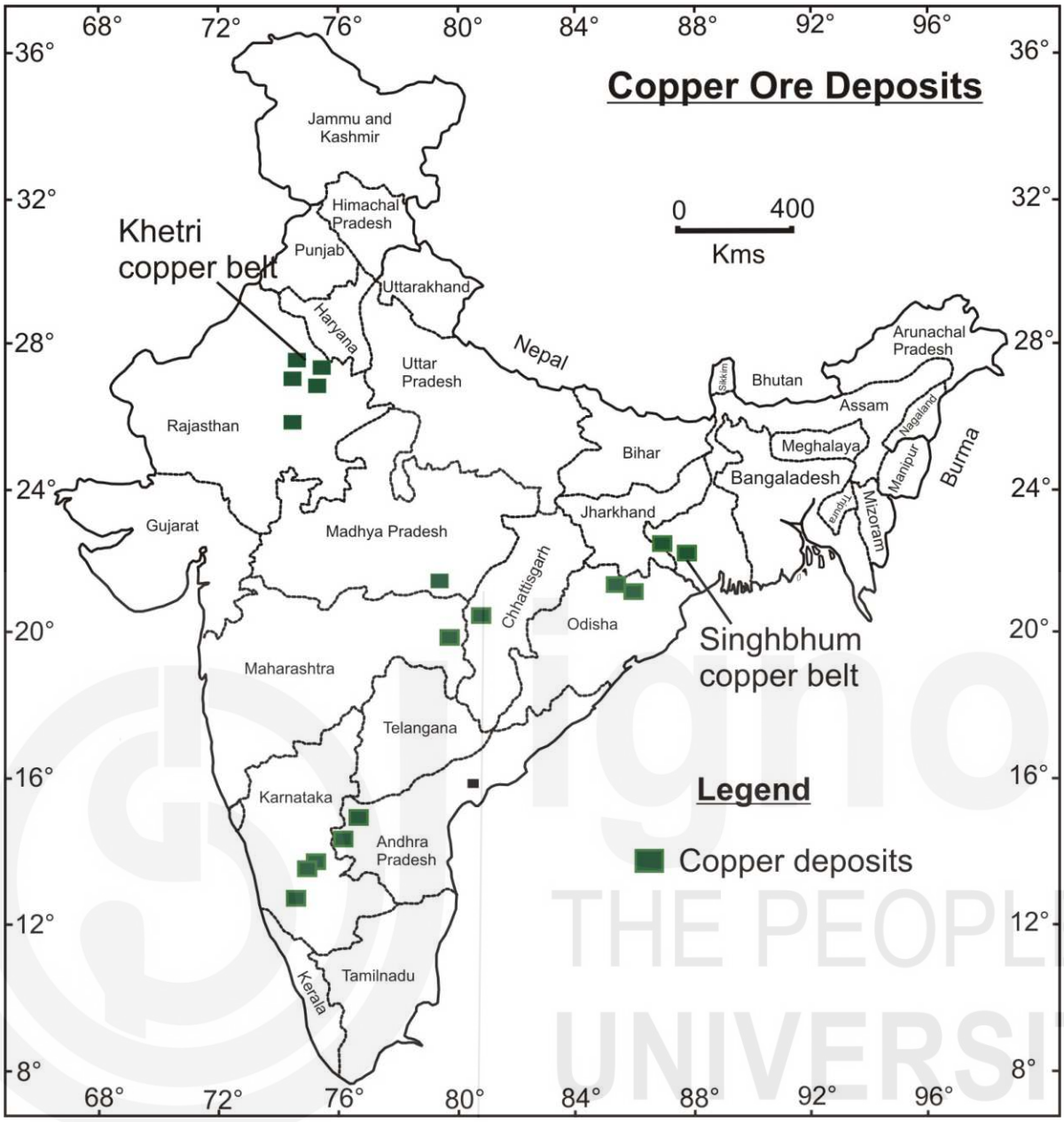


Fig. 13.9: Distribution of copper deposits in India. (modified after Deb and Kaur, 2004)

Fig. 13.10: Sample of chalcopyrite from Malanjkhand copper mine.

SAQ 1

a) List four ore minerals of iron with oxide composition.

b) What is BIF?

c) List ores of manganese.

d) What are ferromanganese nodules?

e) What are base metals?

f) List five ores of copper.

13.5 LEAD AND ZINC

After having discussed about copper let us learn about lead and zinc which are also base metals.

Lead and zinc always go together because of their strong geochemical affinity. Zinc is vital for galvanising industry while battery sector is known for being the major consumer of lead.

13.5.1 Chief Ores

The most common lead ore mineral is galena (Fig. 13.11a). Other ore minerals containing lead are cerussite and anglesite. The metal zinc generally occurs most commonly with lead apart from combination with other elements. The most common zinc ore mineral is sphalerite or zinc blende. Other important minerals of zinc are smithsonite and zincite (Fig. 13.11b).

(a) (b)

Fig. 13.11: Hand specimens of Pb-Zn ores from Zawar mines: a) Ore of lead-galena; and b) Ore of zinc-zincite.

The chief ores of lead with their physical properties are given in Table 13.5.

Table 13.5: Chief ores of lead.

Ores	Composition	Tenor (Pb %)	Physical properties
Galena	PbS	86.6	Colour- light lead grey, dark lead grey Streak- greyish black Hardness-2.5; Sp. Gr.- 7.5
Cersussite	$PbCO_3$	77.5	Colour- colourless, white, grey Streak- white Hardness-3-3.5 Sp. Gr.- 6.55
Anglesite	$PbSO_4$	68.3	Colour- blue, colorless, green, grey, yellow Streak- white Hardness-2.3-3; Sp. Gr.-6.4

The metal zinc generally occurs in combination with other elements, most commonly with lead. The chief ores of zinc with their physical properties are given 3 in Table 13.6.

Table 13.6 Chief ores of zinc.

Ore mineral	Composition	Tenor (Zn %)	Physical properties
Sphalerite	ZnS	67.1	Colour-yellow, light to dark brown, black, light blue Streak- pale yellow to brown. Hardness-3.5-4; Sp. Gr.- 3.9 - 4.2
Smithsonite	$ZnCO_3$	52	Colour- greyish white, dark grey, green, blue, yellow Streak- white Sp. Gr.-4-4.5
Zincite	ZnO		Colour- yellow, dark yellow, dark red, orange Streak-yellowish orange Hardness-5.5 Sp. Gr.-5.5

13.5.2 Process of Formation

Majority of the lead ore deposits of the world are also zinc producers and most zinc ore deposits carry lead. Both lead and zinc bodies usually occur as veins and massive or tabular lodes, and as disseminations and patches, commonly in

limestone or dolomites and shales. Majority of lead-zinc ores in India occur in number of ways like hydrothermal lodes or veins or disseminations, cavity and joint fillings and metamorphic deposits. The contact metasomatic replacement deposits are mostly hosted in limestone or dolomite. The chief modes of occurrence are as lodes or veins, as cavity or joint fillings. Ore deposit in Zawar mine in Rajasthan state occur in fine grained, gritty conglomeratic dolomite with subordinate interbedded phyllite and quartzite. While in the Hesatu-Balbathan belt in Jharkhand ore deposits occur in calcsilicate rocks. The deposits may possibly have formed by the hydrothermal fluid of igneous origin, by descending surface water or by ascending artesian meteoric waters.

13.5.3 Distribution in India

Important deposits of lead and zinc are confined to Rajasthan, Jharkhand, Maharashtra and Andhra Pradesh (Fig. 13.12). They are distributed widely in India, with the major part of the resources~ over 80% are confined to Rajasthan. Other states with minor lead-zinc resources occur in Odisha, Gujarat, Sikkim, Uttarakhand, and Jammu & Kashmir.

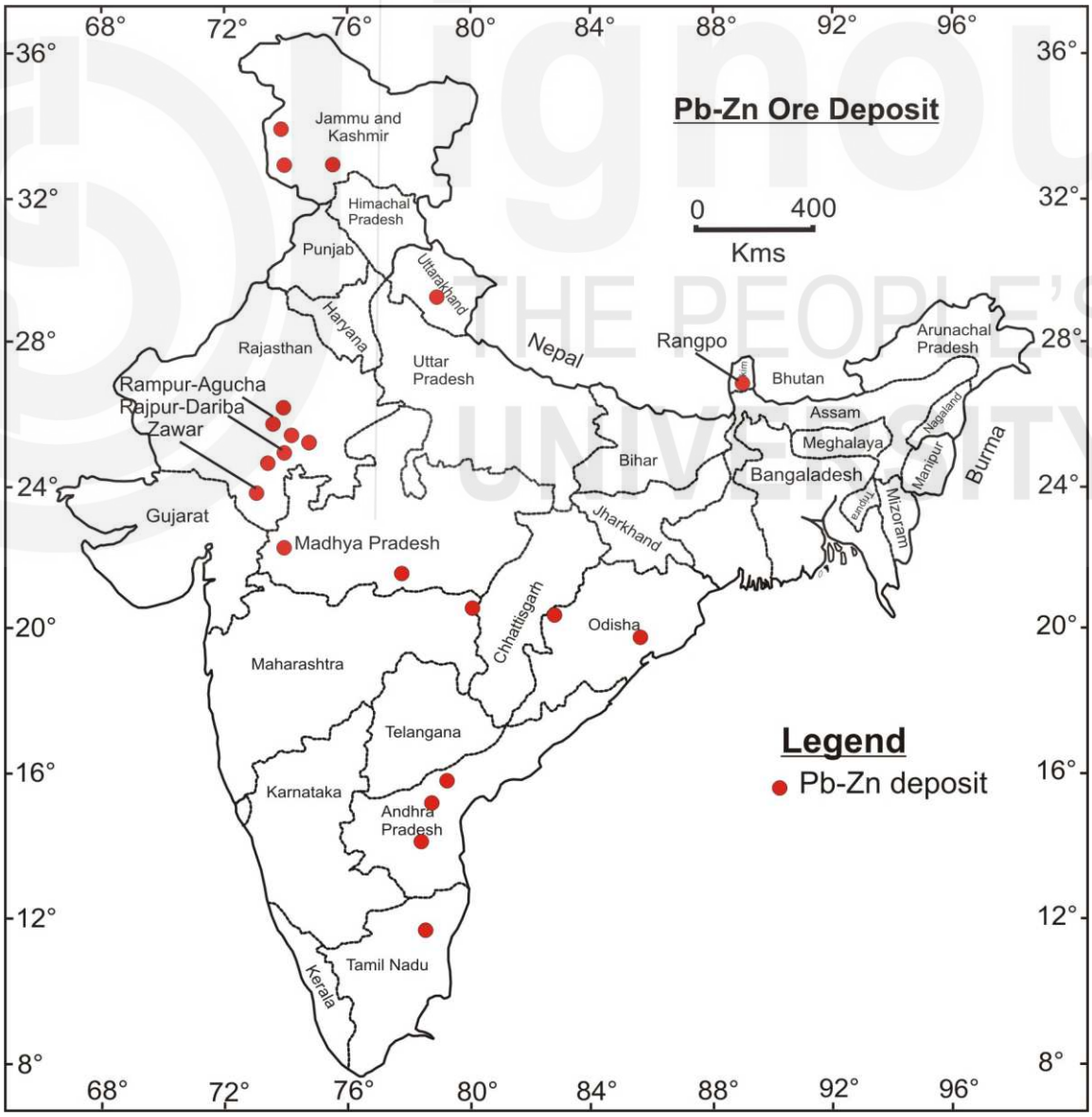


Fig. 13.12: Distribution of lead-zinc deposits in India. (modified after Deb and Kaur, 2004)

The most important zinc-lead deposits of economic value in India are as follows:

- Rampura-Agucha in Rajasthan is a zinc-lead sulphide deposit located in the Bhilwara belt which is mostly metamorphosed dolomite.
- Rajpura-Dariba and Zawar deposits are found in Bhilwara, Rajsamand and Udaipur Districts of Rajasthan respectively. The main sulphide minerals are sphalerite, pyrite and galena.
- Sargipalli mine in Odisha state mined ores like galena, chalcopyrite, sphalerite, cerussite, azurite, malachite and covelite. Sargipalli mine has been closed since 2001-02.
- Agnigundala belt is in Guntur District in the Nallamalai hill range of Andhra Pradesh. The mineralisation is in the form of veins and stringers of galena associated with sphalerite, chalcopyrite and pyrite. The host rock is brecciated dolomite, dolomitic limestone and calcareous quartzites.
- Hesatu-Belbathan belt in Jharkhand is a multi metal belt with mineralisation of Pb-Zn-Cu ores.
- Ambamata deposits hosts polymetallic Zn-Pb-Cu ore lenses are found around Ambaji in the Sirohi District of Rajasthan. These ores occur in metamorphosed basalt-rhyolite bimodal volcanic suite.

13.5.4 Uses

Now let us discuss the uses of lead and zinc which are enormous and rank next to copper as essential non-ferrous metals in the modern industry (Table 13.7).

Table 13.7: Uses of lead and zinc.

SN	Uses of lead	Uses of zinc
1.	Used in car batteries, pigments, ammunition, cable sheathing, weights for lifting, weight belts for diving, lead crystal glass, radiation protection	Used as coating and galvanising iron and steel products to prevent rusting. Galvanised steel is used for car bodies, street lamp posts, safety barriers and suspension bridges
2.	It is corrosion-resistant therefore used in water pipes, chemical plants, ammunitions and nuclear shield in atomic plants	Used to produce die-castings, which are important in the automobile, electrical and hardware industries.
3.	Used in manufacture of insecticides, hair dyes and as an anti-knocking additive for petrol	As component in alloys like brass, bronze, nickel silver and aluminium solder and German silver
4.	Often used to store corrosive liquids. It is also sometimes used in architecture, for roofing and in stained glass windows.	Used to precipitate gold from cyanide solutions in the treatment of gold ores
5.	Pigments, glass, flux and rubber industries	Zinc oxide is widely used in the manufacture of many products such as paints, rubber, cosmetics, pharmaceuticals, plastics, inks, soaps, batteries, textiles, electrical equipment, luminous paints, fluorescent lights and X-ray screens

Watch the following video to more about the formation of zinc ore such as sphalerite by hydrothermal process

- **Hydrothermal mineralisation**

  Link: http://egyankosh.ac.in//handle/123456789/53461

13.6 ALUMINIUM

We have learnt about chief ores, processes of formation, distribution in India and uses of iron, manganese, copper, lead and zinc in the previous section. Now in this section let us discuss about aluminium. India is endowed with rich bauxite resources. India has flourishing aluminium industry next to Japan.

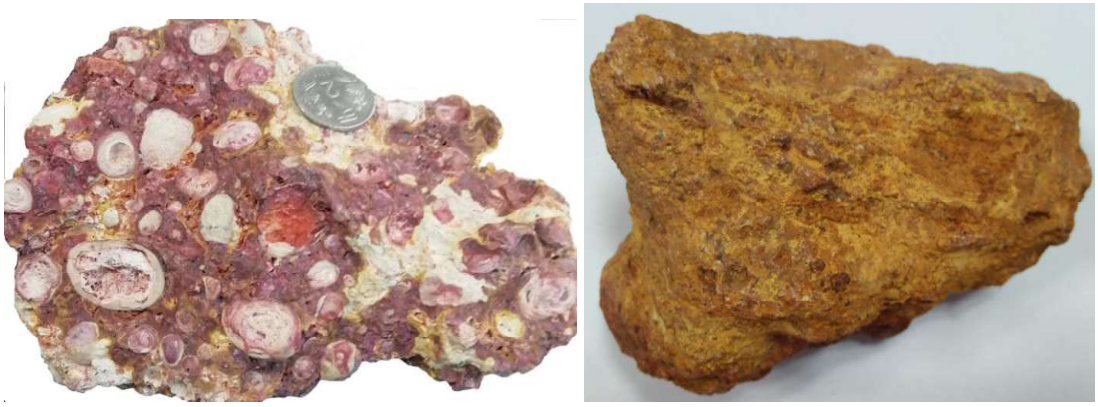
13.6.1 Chief Ores

Aluminium is extracted from bauxite ore (Fig. 13.13a and b) which may contain one or more of the aluminous minerals. Other ores are gibbsite, boehmite or diaspore (Table 13.8).

Table 13.8: Chief ores of aluminium

Ore mineral	Composition	Tenor (Al %)	Physical properties
Diaspore	$Al_2O_3.H_2O$	85	Colour- white, greenish grey, greyish brown, colorless, yellow Streak- white Hardness-nearly 7; Sp. Gr.-3.5
Bohemite	$Al_2O_3.H_2O$	84.98	Colour- white, light yellow, yellowish green Streak- white Sp. Gr.- 3.03
Bauxite	$Al_2O_3.2H_2O$	73.9	Colour-white, grey, sometimes stained yellow, orange, red, pink, or brown by iron Streak- Usually white, but iron stain can discolor Sp. Gr.- 2 to 2.5
Gibbsite	$Al_2O_3.3H_2O$	65.4	Colour- White, light grey, light green, reddish white Streak-white Hardness-2.5-3.5 Sp.Gr.-2.38-2.42

Bauxite ore frequently shows pisolitic and oolitic structure. Pisolite is an accretionary body in a sedimentary rock resembling a pea in size and shape (Fig. 13.13).



(a) (b)

Fig. 13.13: Bauxite ore showing a) Pisolitic structure; and b) Granular structure.

13.6.2 Processes of Formation

Bauxites are formed by the laterisation of igneous (excepting ultramafic), sedimentary and metamorphic rocks. Any rock can act as the protolith for bauxite deposit provided it contains substantial amount of Al_2O_3. As rule, the older bauxites are bohemite and diaspore rich while the younger ones are gibbsitic. The process of **bauxitisation** is primarily related to processes of mechanical disintegration, chemical weathering, and leaching under favourable hot and humid climate. Heavy rainfall and good drainage accelerate the process. The bauxite deposits may be produced by chemical sedimentation, by solution and redeposition, chemical replacement of pre-existing rocks, subaerial weathering *in situ* or detrital deposition, from high altitude to low lying areas. Bauxite occurs as:

1) blanket deposit
2) interlayered deposit
3) pocket deposit, and
4) detrital or transported deposits.

Blanket or upland deposits occur as caps in plateau areas in tropical and subtropical regions for example in Eastern and Western Ghats. Interstratified deposits occur as beds or lenses in stratigraphic sequences. Pocket deposits are also known as karst bauxites. They are restricted to calcareous rocks and occur as isolated pockets. Transported deposits are removed from the place where they are originated. When the original deposits are reworked, transported and redeposited then the transported bauxite deposits are formed.

13.6.3 Distribution in India

Large resources of low-grade bauxite ores have been explored by Government agencies on known aluminous laterite occurrences (Krishnan, 1935). Bauxite occur in the Eastern Ghat belt from East Godavari District of Andhra Pradesh to Sambalpur and Bolangir Districts of Odisha covering an area of almost 25,000 sq.km (Fig. 13.14). The bedrocks of granulite comprising an interlayered sequence of khondalites and leptynites of Precambrian age have given rise to blanket-type bauxite deposits with large aerial extent and appreciable thickness. The well-known aluminous laterite occurrences in the East Coast Bauxite Province are at Anantagiri

area in Vishakhapatnam District of Andhra Pradesh where bauxite cappings at altitudes of 1090 to 1445 m are found at Galikonda, Raktakonda, Katuki and Chittamgondi. In Odisha, aluminous laterite deposits occur at Pottangi, Panchpatmalli and Baphlimalli hills in the Koraput District, around Kashipur in Kalahandi District and on the Gandhamardan plateau of Bolangir District. A rough estimate of the bauxite resources in the East Coast bauxite province is of the order of one billion tonnes of aluminous laterites with about 40% Al_2O_3.

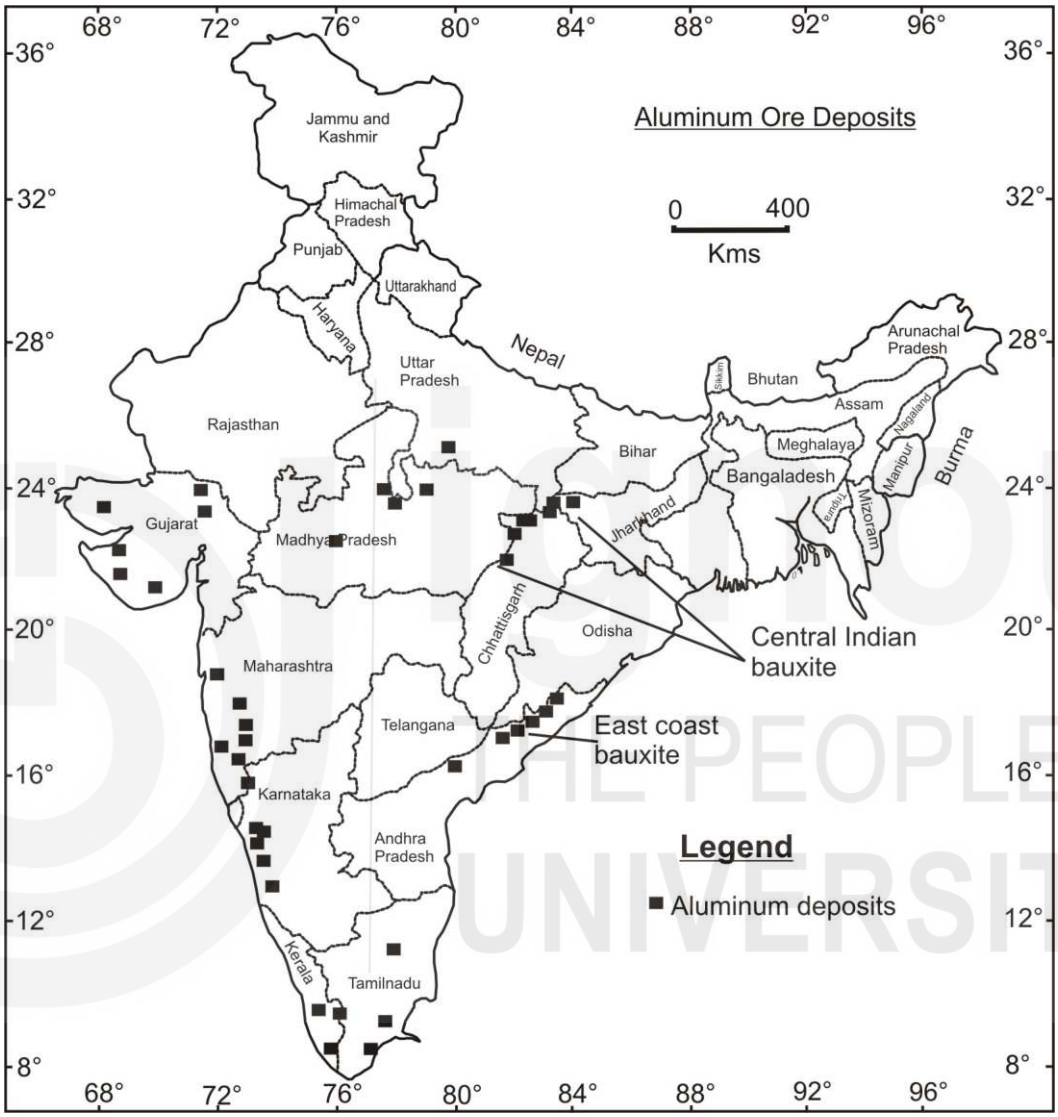


Fig. 13.14: Distribution of aluminum deposits in India. (modified after Deb and Kaur, 2004)

Bauxite belt of Central India about 400 km long and 50 km is sub-parallel to the south of the Son-Narmada lineament, extending from Madhya Pradesh through Chhattisgarh to Jharkhand. Bauxite deposits occur at Balaghat, Amarkantak, Putkapahar and Mainpat, Jamirpat, Bagru-Manduapat-Neturhat. They have high grade bauxites with Al_2O_3 content varying between 49.7 and 60%. There are three main bauxite-producing areas in Madhya Pradesh and Chhattisgarh. These are:

- Sarguja-Raigarh-Bilaspur Districts,
- Ranchi, Palamau, Shahdol, Durg, Mandla and Balaghat Districts, and
- Katni-Newer-Jabalpur areas of Jabalpur Districts.

Rich bauxite deposits with high alumina, high silica and iron occur on bedrocks of Deccan traps in Belgaum District in Karnataka. The bauxite occurs as thick, uniform capping on Deccan basalts on the plateau. The uniform thickness of the capping well-defined scarps, and marginal nudges give a distinctive feature to the topography.

13.6.4 Uses

Metallic aluminium is light weight and has 60% of the electrical conductivity of copper. It is used for making alloys with copper, zinc, magnesium and manganese. This markedly improves its mechanical properties and renders it light weight and strength. It is very important in the construction of aeroplanes and other forms of transport.

Aluminium is used for making aluminium foils and beverage cans, kitchen utensils and window frames. It is also used to produce 'cement fondu', aluminous cement characterised by rapid hardening qualities. The non-toxic nature of aluminium makes it safe to use to make cooking tools such as spatulas and whisks.

Aluminum forms a highly reflective coating for both light and heat when evaporated in a vacuum. It does not deteriorate, like a silver coating. The aluminum coatings have many uses such as in telescope mirrors, decorative paper, packages and toys.

13.7 GOLD

We have discussed about aluminium in the previous section. Now let us learn about a precious metal like gold. Gold has the yellow radiant colour and high reflectance. It is also highly malleable and ductile and has high specific gravity. The usage of gold use has been traced back to more than 6000 years ago.

13.7.1 Chief Ores

Gold occurs principally as a native metal. Native gold can occur as sizeable nuggets, as fine grains or flakes in the alluvial deposits. Ores in which gold occurs in chemical composition with other elements are comparatively rare.

Fig. 13.15: Native gold. (source: www.usgs.gov)

13.7.2 Processes of Formation

The primary and secondary processes produce gold concentrations in nature. Fluids play a key role in concentrating gold in both these environments. In early Archean times, Mg-Fe-rich or ultramafic lavas reacted with sea water creating primary greenstones and concentrating gold along with nickel, copper and iron. The

subsidence and tectonism caused partial melting and differentiation of the primary greenstones and gave rise to silica-rich plutonic rocks. They had more gold abundance than their precursors. This was followed by hydrothermal activity which leached the metal and concentrated it in lodes to produce the gold-quartz veins. While primary mineralisation served as the principal source of gold for several centuries, of late, gold concentrations associated with low temperature processes in supergene environment have been located in laterites in South America, South Africa, Western Australia, Madagascar and Southern India. Gold eroded from primary ore deposits also commonly accumulates as detrital particles and form placer deposit. The origin of this large gold resource however, is debatable in recent years with two strong opposing views: sedimentary (diagenetic) and hydrothermal.

13.7.3 Distribution in India

Most known primary auriferous zones in India are the vein type deposits located in the eroded remnants of ancient volcano-sedimentary rocks. They are known as schist belts or greenstone belts of late Archaean age in the Dharwar Craton, South India (Fig. 13.16) such as Kolar, Hutti, Gadag. Thus, the largest cluster of gold occurrences is located in the states of Karnataka and Kerala. Gold is also known to have high potential in South Jharkhand, parts of Madhya Pradesh and in South Rajasthan.

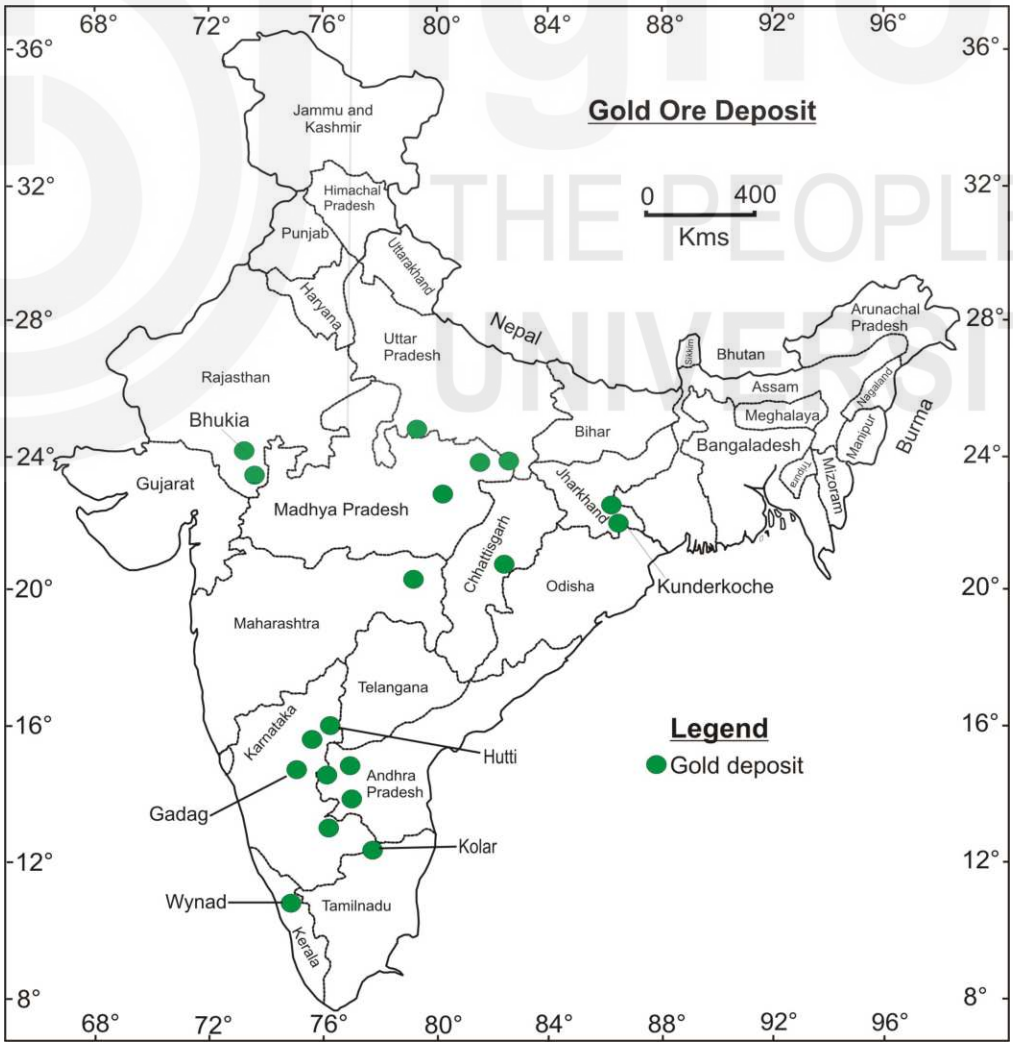


Fig. 13.16: Distribution of primary gold deposits in India. (modified after Deb and Kaur, 2004)

Gold occurs in a variety of geological settings. The following modes of occurrences are recorded in India (Radhakrishna and Curtis, 1999):

1. Lode Gold (quartz–carbonate vein type) deposits
2. Gold in banded iron formation
3. Gold in granulite terrain
4. Disseminated gold (Fig. 13.17)
5. Gold associated with Palaeoproterozoic volcanic or sediment-hosted polymetallic sulphide deposits
6. Gold in quartz pebble conglomerates and quartzites (ancient placers)
7. Greywacke or turbidite-hosted deposits
8. Carbonate-hosted gold deposits
9. Gold in coal
10. Epithermal bonanza type deposits of Tertiary age
11. Placer and alluvial gold
12. Gold in laterite, soil and weathering profiles

Fig. 13.17: Disseminated gold occurrence in quartz. (Source: www.gsi.gov.in)

13.7.4 Uses

Most of the gold produced goes into the monetary reserve and forms a monetary base for currency. Gold is extensively used in jewellery and also finds its utilisation in textile industry for Zari work. God is also used in chemical industry, medicine, dentistry, laboratory equipments, electrical components and crockery. Gold is also used for therapeutic purposes, in dentistry and specialised equipments.

13.8 RADIOACTIVE METAL GROUP

After having discussed about the ferrous, base, light and precious metals in previous sections let us discuss about radioactive metals like uranium and thorium.

Uranium and thorium are the members of the actinide (Ac) series. In the Periodic Table, U is the first member of Group VI B and Th is the last element in Group IV B. Both Th and U are markedly oxyphilic which means close affinity to oxygen, amongst anions. They are also biophilic due to this they concentrate in organic compounds like humus, coal, petroleum and bitumen.

13.8.1 Chief Ores

The chief ores of uranium are given mentioned in Table 13.9.

Table 13.9: Chief ores of uranium.

Ore mineral	Composition	Colour
Pitchblende	$2UO_3.UO_2$	Black, brownish-black
Torbernite	$CU(UO_2)P_2O_8\ 12H_2O$	Green, grass green, leek green, apple green,
Autunite	$Ca(UO_2)_2.P_2O_8.8H_2O$	Yellow, pale yellow, lemon yellow, greenish yellow, pale green.
Carnotite	$K_2O.2U_2O_3\ V_2O_5.2H_2O$	Bright yellow
Uraninite	UO_2	Brownish black, grey, greyish black, black.

Thorium is grey heavy, hard to fuse, and emits radiations. Like uranium it is not found in native state in nature because of their highly active nature. The chief ore minerals of thorium are given below in the Table 13.10.

Table 13.10: Chief ores of thorium.

Ore mineral	Composition	Colour
Monazite	$(Ce,La,Nd,Th)PO_4$	Brown, colorless, greenish, grey white, yellow
Thorite	$(Th,U)SiO_4$	Black, but also brownish black, orange, yellowish-orange and dark green
Thorianite	$ThO_2.U_3O_8$	Brownish black, green, green black, grey green, yellow

13.8.2 Process of Formation

Uranium and thorium are widely disseminated in the Earth's crust but rarely form huge deposits of rich ores. Upper layers of the Earth's crust contain 100,000,000 million tonnes of uranium. They appear as primary constituents of igneous rocks, granites and pegmatites or in high temperature veins associated with tin, copper and lead minerals or accumulate in ores of hydrothermal deposits. Uranium and thorium also occur as secondary products associated with other minerals (Fig. 13.18). Primary uranium and thorium minerals in veins and igneous rock masses are converted in the surface oxidation zone into secondary minerals. They are easily soluble and are carried by rivers into seas and lakes.

Fig. 13.18: Secondary uranium associated with black shale. (Source: www.gsi.gov.in)

13.8.3 Distribution in India

The occurrence of uranium deposits in India may be classified as:

- Disseminated type
- Vein type
- Infillings in fault breccia

They all occur in the Precambrian rocks of Dharwar Craton in southern part of India. Uranium is also associated with copper mineralisation but not all copper carry uranium. Geographically, uranium ores are known to occur in several localities along the Singhbhum copper belt and the Aravalli rocks in Udaipur District. Thorium along with uranium occurs in the cerium rich monazite mineral. This mineral is a constituent of the heavy black sands on the sea coasts of India, from Narmada estuary to Kerala coast and Odisha coast. The uranium mine in Jaduguda village in the Singhbhum District of Jharkhand was the first uranium mine in India.

13.8.4 Uses

These minerals are used as raw material in nuclear plants. The chemical industry uses nuclear reaction products to speed up chemical process and to obtain new compounds such as plastics. The disintegration of uranium and thorium minerals gives rise to radium which is important in the treatment of cancer, in certain X-ray apparatus and for luminous paint. These two minerals are used in research, industry, agriculture and medicine.

In the previous sections we have discussed in details about metals like iron, manganese, copper, lead, zinc, aluminium and gold. Before reading about radioactive metals in the next section spend 5 minutes to check how you are progressing.

SAQ 2

a) List chief ores of lead and zinc.

b) List uses of lead and zinc.

c) Mention chief ores of uranium and thorium.

d) List the mode of occurrence of uranium deposits in India.

e) List uses of radioactive metals.

13.9 SUMMARY

In this unit, you have learnt about various types of metallic ore deposits, their processes of formation, distribution in India and uses. Now let us summarise about what we have learnt in this unit:

- Iron ores can be grouped into oxide, hydroxide, carbonate, silicate based on the chemical composition. Iron ore deposits can form by magmatic, sedimentary and metamorphic processes. The distribution of Indian iron ore deposits can be grouped into four categories based on their origin and mineralisation.

- Manganese occurs in the form of oxides, carbonates and silicates occur in diverse geological settings and form by processes like hydrothermal activity, sedimentation, metamorphism and continental weathering.
- Indian manganese ore deposits occur mainly as metamorphosed bedded sedimentary deposits associated with Gondite Series of Madhya Pradesh and Kodurite Series of Odisha.
- Copper deposits have originated by diverse processes like magmatic segregation, hydrothermal activity, submarine exhalations, bacteriogenic precipitation and oxidation and supergene enrichment.
- Rich copper deposits are found in Singhbhum thrust belt and Khetri copper belt in Jhunjhunu District. Malanjkhand mine is the biggest open pit base metal mine in India located in Balaghat District of Chhattisgarh state
- The chief ores of lead are galena and cerussite and zinc are sphalerite, zincite and smithsonite. Majority of lead-zinc ores in India occur in number of ways like hydrothermal lodes or veins or dissemination, cavity and joint fillings and metamorphic deposits. Important deposits of lead and zinc are confined to Rajasthan, Jharkhand, Maharashtra and Andhra Pradesh.
- Aluminium is extracted from bauxite ore which may contain one or more of the aluminous minerals like gibbsite, boehmite or diaspore. The process of bauxitisation is primarily related to processes of mechanical disintegration, chemical weathering, and leaching under favourable hot and humid climate. Rich bauxite deposits occur on bedrocks of Eastern Ghats, Western Ghats and Deccan traps.
- Gold occurs principally as a native metal. The primary and secondary processes produce gold concentration in nature. Largest cluster of gold occurrences is located in the states of Karnataka and Kerala.
- Th and U are markedly oxyphile, they have also biophile tendency. Due to this, they concentrate in organic compounds like humus, coal, petroleum and bitumen.

13.10 ACTIVITY

- Make a list of ferrous, base, light and precious metals
- Find out the places and list the metallic ore deposits that are found in your state. You can take help of the websites of Geological Survey of India, Indian Bureau of Mines and Directorate of Geology and Mining of your state.
- Find out the places in India where Uranium and Thorium deposits occurs.

13.11 TERMINAL QUESTIONS

1. Discuss the processes of formation of iron ore deposits.
2. List the common uses of iron and manganese.
3. Discuss the processes of formation of copper deposits and their distribution in India.
4. Discuss the processes of formation of lead and zinc deposits and their distribution in India.

5. Explain the process of formation of aluminum ores.
6. List different geological settings reported for the occurrence of gold in India.

Audio/video material based questions

- What are the metallic ore deposits formed due to contact metasomatism?
- Explain copper ore deposits are formed by contact metasomatism.
- Mention about the magmatic concentration processes responsible for formation of titaniferous magnetite deposits.
- Which magmatic concentration process forms the chromite deposit?

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13.14 ANSWERS

Self Assessment Questions

1 a) Limonite, magnetite, goethite, hematite.

b) BIF are extensive thick sequences of Precambrian age. They are laminated with fine grained hematitic layers interbedded with chert/jasper/quartzite.

c) Pyrolusite, psilomelane, rhodochrosite and rhodonite.

d) Ferromanganese nodules are found in the deep ocean floor of Indian Ocean. The deep sea nodules form future resource of manganese and some other important metals such as cobalt, nickel, copper etc.

e) Copper, lead and zinc.

f) Please refer Table 13.3.

2 a) Lead-cerussite and anglesite. Zinc-sphalerite or zinc blende, smithsonite and zincite.

b) Please refer Table 13.5.4.

c) Please refer subsection13.8.4

d) Uranium-Pitchblende, Torbernite, Autunite, Carnotite, Uraninite

e) Thorium-Thorianite, Thorite, Monazite

f) Disseminated type, vein type, infillings in fault breccia.

g) Please refer subsection 13.8.4.

Terminal Questions

1. Please refer to the subsection 13.2.2. Hint: Discuss about metamorphic banded deposits, continental sedimentary deposits, marine sedimentary deposits, detrital, placer and mixed type, volcano sedimentary deposits, liquid magmatic deposits, contact metasomatic deposits, intrusive magmatic deposits, contact metasomatic deposits.
2. Please refer to the subsection 13.2.4 and 13.3.4.
3. Please refer to the subsection 13.4.2 and 13.4.3.
4. Please refer to the subsection 13.5.2 and 13.5.3.
5. Please refer to the subsection 13.6.2.

6. Lode Gold (quartz–carbonate vein type) deposits; Gold in banded iron formation; Gold in granulite terrain; Disseminated gold; Gold associated with Palaeoproterozoic volcanic or sediment-hosted polymetallic sulphide deposits; Gold in quartz pebble conglomerates and quartzites (ancient placers); Greywacke or turbidite-hosted deposits; Carbonate-hosted gold deposits; Gold in coal; Epithermal bonanza type deposits of Tertiary age; Placer and alluvial gold; and Gold in laterite, soil and weathering profiles

UNIT 14

NON-METALLIC MINERALS

Structure

14.1 INTRODUCTION

In the previous units of this block we have discussed about ore and ore deposits, and processes of ore formation. Ore minerals have been divided into metallic and non-metallic groups. In Unit 13 we have discussed various kinds of metallic minerals such as ferrous, base, light, precious and radioactive metals, with respect to their ores, processes of formation and distribution in India. The non-metallic minerals (rock salt/halite, soapstone, asbestos, barite, mica, cement, feldspar, gemstones, gypsum) lack the properties of the metallic minerals such as a bright metallic luster, hardness, density, and good conduction of heat and electricity. Non-metallic minerals, including industrial minerals and rocks and building stones form the major part of natural resources used by modern societies. Non-metallic minerals form the back bone of several industries such as chemical, ceramic, fertiliser, refractory, etc. India is endowed with some of the largest deposits of these industrial minerals. Now in this unit we will discuss about the non-metallic minerals used as industrial minerals and building

materials. We will also discuss minerals used in refractory, fertiliser, ceramic and glass manufacturing, chemical and paints, abrasive and gemstone industries (Fig. 14.1).

Expected Learning Outcomes

After reading this unit you should be able to;

- ❖ discuss about industrial minerals like mica, gypsum and magnesite;
- ❖ describe building and construction materials like granite, marble, limestone etc.;
- ❖ explain about minerals used in refractory, ceramic and glass manufacturing industries;
- ❖ discuss minerals used in fertiliser, chemical and paint, and abrasive industries; and
- ❖ list the minerals used as gemstones

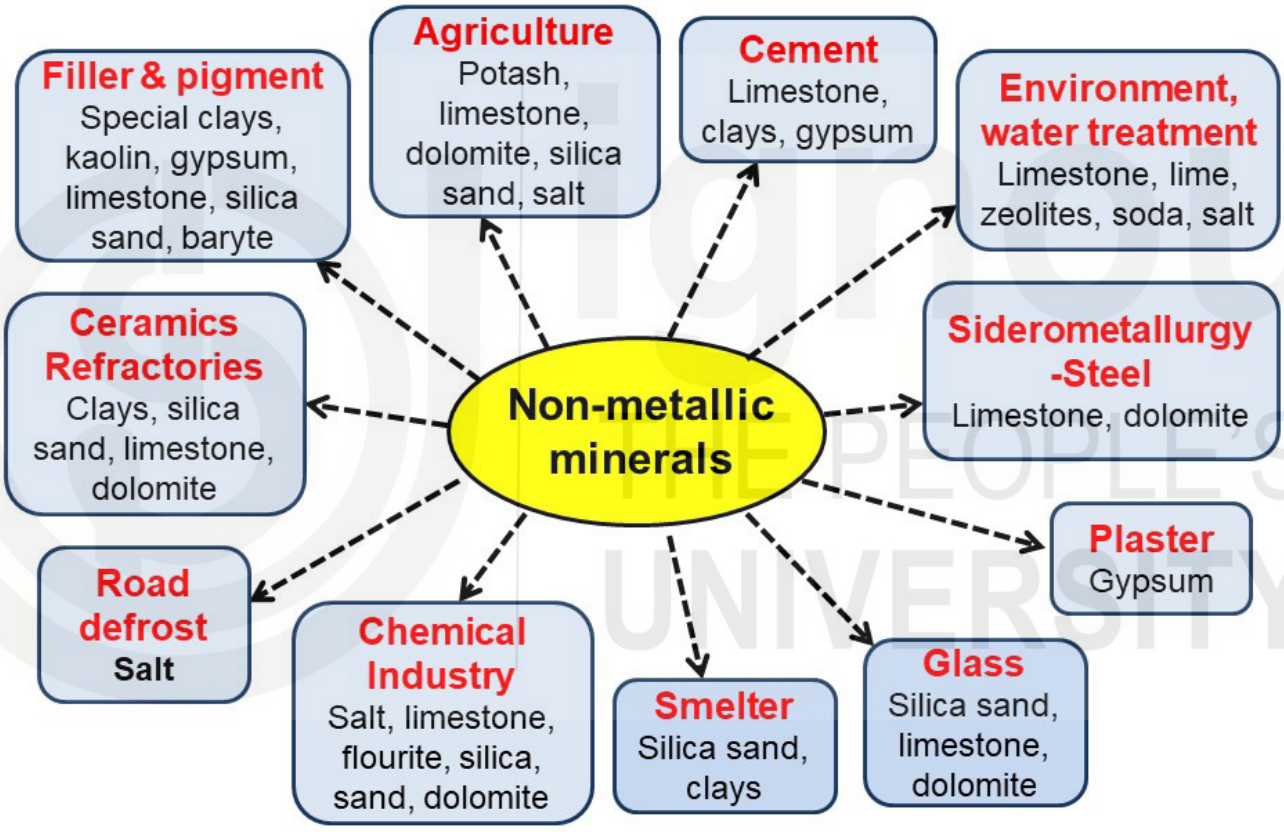

Fig. 14.1: Diversified uses of non-metallic minerals in various industries.

14.2 INDUSTRIAL MINERALS

Man has exploited industrial minerals for many thousands of years which have contributed to several most important cultural developments. Prehistoric man used hard stones for lightening the fire, grinding and cutting. With the advancement of technology industrial materials are being used for various applications. We have read in the previous units that practically all industrial minerals contain metallic elements and they are often confused with non-metallic. It must now be noted that many 'metallic ores', such as bauxite, ilmenite, chromite and manganese minerals are also important raw materials for industrial mineral. Many definitions have been given for industrial minerals

for example Bates (1994) defines them as “an industrial mineral is any rock, mineral, or any other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels and gemstones; one of the non-metallics”. In fact industrial minerals have been used in the past as a synonym to non-metallic materials (Harben and Bates, 1990). However, there are two shortcomings in this definition, firstly there are several metallic ores such as bauxite, ilmenite, pyrite and Fe-oxides which come in the category of industrial minerals. Secondly the term industrial minerals can be used also for manufactured materials such as cement, refractories or abrasives. The definition is given by Scott (2009) takes care of these aspects. According to him “industrial minerals are a loose grouping of products made from Earth materials that are not a source of a metal or energy”.

According to a definition “industrial minerals and rocks are utilised because of their important physical and chemical properties either as raw materials or after processing. These properties remain essentially unchanged in the end use after processing” (Bates, 1969).

A number of industrial rocks and minerals are utilised for industrial purposes**.** Important among them are mica, asbestos, barites/talc/soapstone, asbestos, barite, calcium carbonate, diatomite, feldspar, gypsum, kaolinite, silica, talc.

Let us discuss some industrial minerals like mica, magnesite and gypsum.

14.2.1 Mica

India is endowed with huge deposits of mica which enable us to dominate the demand of world’s market in the field of electrical industry. Most of the countries in world are dependent upon India for quality mica sheets and splitting. We have read about the mica minerals in block 2 of this course. Let us recall the minerals of mica group (Fig 14.2 and Table 14.1).

Table 14.1 Chief Minerals of Mica group.

S.N.	Minerals	Commercial name	Composition
1.	Muscovite	Potassium mica/white mica/ruby mica	$KAl_2(AlSi_3O_{10})$
2.	Paragonite	Sodium mica	$NaAl_2(Si_3Al)O_{10}(OH)_2$
3.	Phlogopite	Magnesium mica/amber mica	H_2KMg_3 Al $(SiO_4)_3$ with flourine
4.	Biotite	Magnesium iron mica/black mica	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$
5.	Lepidolite	Lithium mica	$(OH,F)_2KLiAl_3$ $(AlSi_3)O$
6.	Zinwaldite	Lithium-iron mica	Li, Fe, K, F in addition to Al and SiO_2

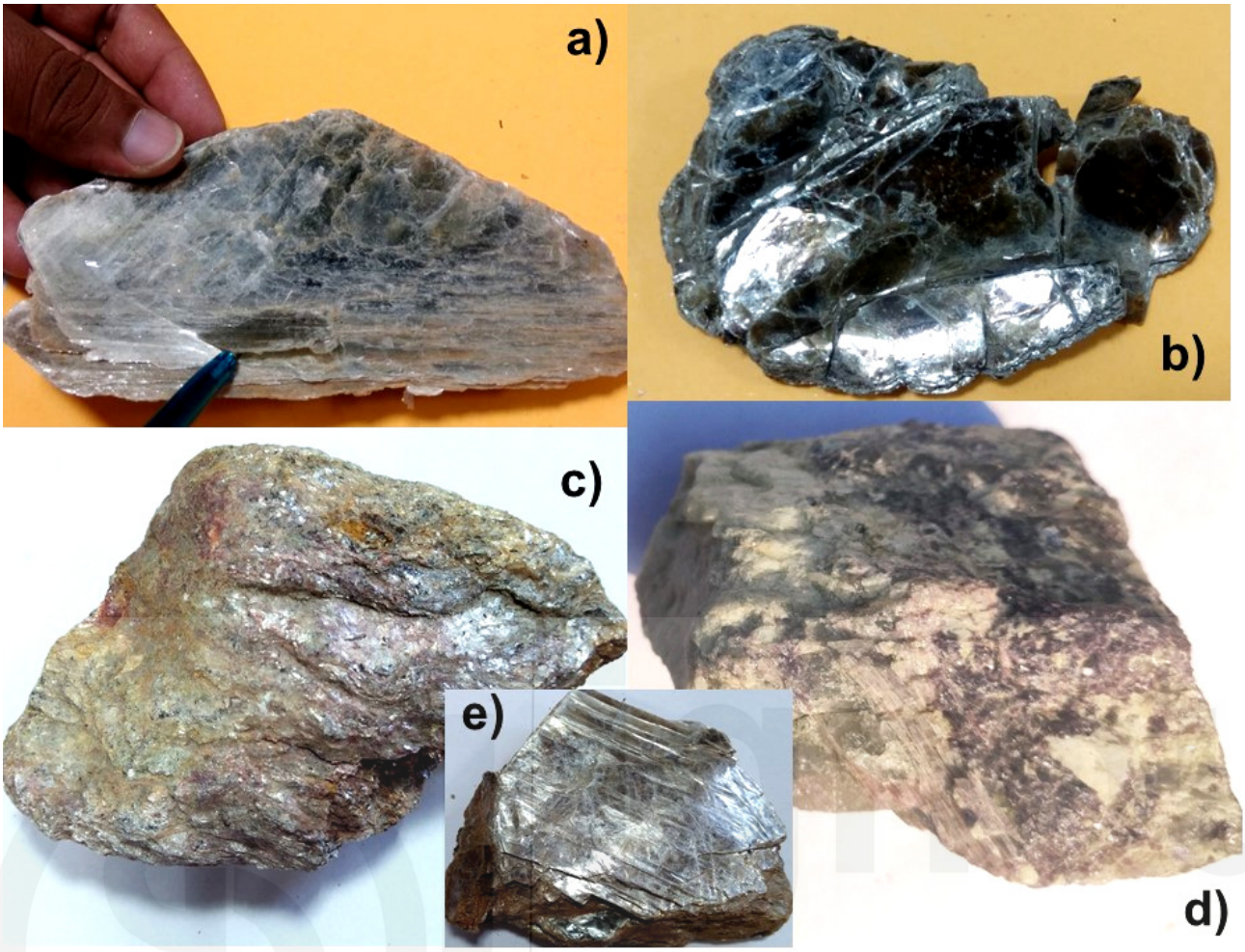

Fig. 14.2: Mica minerals: a) Muscovite; b) Biotite; c) Phlogopite; d) Lepidolite; and e) Paragonite.

Mode of occurrence and origin: Mica forms from late magmatic solutions in the pegmatites. Pegmatites are composed normally of plagioclase feldspar and quartz, though in some places minerals like tourmaline, garnet, apatite and rarely beryl may occur. Muscovite occurs in silicic pegmatite, in association with granitic intrusive. Phlogopite comes from quartz-free pegmatites. Biotite is obtained from metamorphic rocks-biotite schists. Lepidolite and zinwaldite are confined to granitic pegmatites. The micas occur as a constituent of pegmatites and veins which penetrate the mica schists. Commercial mica occur as zonally distributed 'books' in the pegmatites. The origin of phlogopite mica is different from that of muscovite where the former forms under the action of gases, vapours and aqueous solutions of granitic magma on magnesium rich host rocks, dolomitised limestone and dolomite.

Distribution in India: In India best quality mica and the workable deposits have been recorded mainly from Jharkhand, Andhra Pradesh and Rajasthan. Occurrences of less importance mica is reported from Tamil Nadu, Karnataka, Kerala, west Bengal, Madhya Pradesh and Odisha. There are three mica belts namely:

- **Rajasthan mica-belt**: This belt extends for about 320 Km from Jaipur to Udaipur District through Ajmer, Bhilwara, Tonk and Pali Districts with average width of 96 Km. The mica pegmatites occur as intrusive in the gneisses and schists of Archaean age.

- **Bihar mica-belt**: Its potential areas are around Koderma, Giridih and Chakai. This belt has average width of 20 Km and extends from Gaya through Hazaribagh and Munger Districts to Bhagalpur District. The country rock is mica schist of Archaean age.
- **Mica schist belt of Andhra Pradesh**: This belt has average width of 16 Km extending about 96 Km with main deposits at Kalichedu, Thalpur, Gudur and Sangam in Nellore District.

Uses: The flaky nature and splitting property of mica combined with its flexibility, elasticity, toughness, resilience, low heat conductivity and high dielectric strength make the mica excellent electrical insulators. High quality natural sheet mica is used in helium neon laser as retardation plates. Sheet mica are also used in electrical and electronic industries as insulating materials, such as capacitors, communicator segments, and high-pressure steam boilers. Mica powder is used in wall paper, automobile tyres, moulded insulators, as filler in rubber goods and drill mud. Phlogopite is good for manufacture of sparks plugs of aeroplane and washers for electrodes. Biotite serves as ground mica in ayurveda medicine as 'abhrakha bashma'.

14.2.2 Gypsum

Gypsum ($CaSO_4.2H_2O$) is a hydrated calcium sulphate. It is widely used in industry because of its special property of losing three-fourth of the combined water of crystallisation when moderately heated (calcined) to about 130°C. Gypsum when finely ground and made plastic with water on cooling can be spread out, cast or moulded to any desired surface or form. On drying, it sets into a hard rock-like form. Gypsum has specific gravity of 2.3. It has hardness 2 and can be scratched with finger nail. Indian gypsum is mostly of gypsite type (Fig. 14.3).

Gypsum is required for cement and fertiliser industry. It is categorised into following five types:

1. Rock gypsum,
2. Gypsite, a mixed porous type with sand and clay,
3. Alabaster, a fine grained, massive and light coloured,
4. Satin spar, silky and fibrous form,
5. Selenite, crystalline, colourless, transparent silky form

Mode of occurrence and origin: Gypsum occurs as evaporite deposit and is a common mineral widely distributed in sedimentary rocks, often as thick beds. It frequently occurs interstratified with limestones and shales and is usually found as a layer underlying beds of rock salt. More rarely it may crystallise in veins, forming satin spar. It is also found as tabular bodies or scattered crystals in clays and shales. It occurs in volcanic regions, especially where limestones have been acted upon by sulphur vapours. Also found commonly as a gangue mineral in metallic veins. Usually the deposits have very little or no overburden and the material being very soft and friable are very easy to mine.

Fig. 14.3: Hand specimen of gypsum.

Distribution in India: Gypsum deposits occur in several parts of India. Besides, it is obtained as by product from sea water during processing of common salt and from several chemical plants such as phosphoric acid, hydrofluoric acid, borax and boric acid. Selenite occurs in Nellore and Guntur and Prakasham Districts of Andhra Pradesh. Selenite occurs in Jamnagar, Surendranagar, Bhavnagar, Jamnagar and Kutch Districts of Gujarat. Gypsum occurs in Sirmur and Chamba, of Himachal Pradesh. In Baramula and Doda, Jammu & Kashmir gypsum deposits are associated with marine clays, phyllite and schists. High-grade gypsum is mostly mined in Rajasthan in Nagaur, Bikaner, Barmer, Churu, Jaisalmer and Pali. Gypsum also occurs in Gulbarga District of Karnataka, Shahdol District of Madhya Pradesh and Tiruchirapalli District of Tamil Nadu. Gypsum occurs interbedded with limestone or dolomite in Tehri Garhwal, Dehradun and Nainital Districts of Uttar Pradesh.

Uses: Gypsum is utilised in three important industries like cement, fertiliser (ammonium sulphate) and Plaster of Paris. Gypsum of less purity in crushed form is utilised in Portland cement manufacturing for controlling the setting time of portland cement. Less pure form of gypsum may be utilised as retardant to control the setting time in the manufacture of cement. Gypsum is also used in manufacturing ammonium sulphate fertiliser, pottery, pharmaceuticals, textiles, asbestos products, paints etc. High-purity gypsum may be utilised for manufacturing of ammonium sulphate fertiliser. Ground pure white gypsum is also used as filler in paper, paints and textile goods. Ground low grade gypsum is used in mine dusting, manufacture of black board chalks and as filler in insecticides. Besides, gypsum is also used pharmaceutical, textile industries and also in asbestos products. Selenite, a crystalline variety is used to a limited extent for gypsum plate for petrological microscopes, known as Sensitive Tint. It is also used in the ceramic Industry for making moulds, to manufacture surgical grade Plaster of Paris and also for producing white cement. Plaster of Paris industry requires high purity gypsum.

14.2.3 Magnesite

We have read about mica and gypsum now let us discuss about magnesite.

Magnesite ($MgCO_3$) is a carbonate of magnesium (Fig. 14.4). Commercially the term 'magnesite' refers not only to the mineral, but also to many products, obtained by calcining the natural carbonate, e.g., caustic magnesite (magnesia obtained by calcining crude magnesite at comparatively low temperatures, 700 to 1000°C) and refractory magnesite (magnesia obtained by calcining magnesite at high temperatures, 1500 to 1800°C). Pure magnesite is calcined at still higher temperatures (1600-1800°C) to expel carbon dioxide completely which is known as 'periclase' (MgO) in the trade.

Fig. 14.4: Hand specimen of magnesite.

Mode of occurrence and origin: Magnesite is usually found as secondary deposits formed due to alteration product of ultramafic rocks and other magnesium-rich rock types. It is also formed by replacement of carbonate and dolomitic limestone. It can occur as bedded sedimentary deposits and as irregular veins. Vein type magnesite deposits is hosted by ultramafic rocks in the Chalk hills of Salem, Tamil Nadu. Magnesite deposits in India generally occur as crystalline mass, amorphous and massive. Most common impurities found in magnesite are calcium and silica along with Fe_2O_3 and Al_2O_3. The magnesite deposits generally occur in three forms. They are cryptocrystalline, fibrous and nodular types. Magnesite can also be formed by metasomatism in skarn deposits, in dolomitic limestones, associated with wollastonite, periclase, and talc.

Distribution in India: In India economically rich magnesite deposits are found in Almora and Pithoragarh Districts of Uttar Pradesh. Magnesite deposits are reported in two tehsils, namely, Brahmani and Pangi in Himachal Pradesh. In Jammu and Kashmir

occurrences of magnesite deposits are reported from Kargil, Ladakh and Udhampur Districts. In Karnataka, they are located in the Districts of Coorg and Mysore. Magnesite deposits are reported from Arcot, Dharmapuri, Nilgiris, Periyar, Coimbatore, Tirunelveli, Tiruchirapalli and Salem Districts of Tamil Nadu. The magnesite deposits are mostly associated with ultramafic bodies such as peridotite, dunite and pyroxenite. Massive mining activity is going on the Chalk Hills in Salem. Occurrences of magnesite in Tamil Nadu are low in lime and high in silica, whereas those of Uttarakhand are high in lime and low in silica.

Uses: Magnesite is used as abrasive for soft polishing of metal and mineral surfaces. The refractory industry is the major consumer of magnesite. It is important mineral for the manufacture of basic refractories, which could be largely used in the steel industry. The refractory magnesite and fused magnesia are used in refractory industry to manufacture various refractory products. Fused magnesia finds application as insulating material in tubular heating elements in electrical Industry and refractory brick linings in steel furnaces. Magnesite is used as raw material in mosaic tiles, electrodes and manufacture of magnesium metal. It is also used in fertilisers and food processing industry. The caustic magnesia is used as animal feed stuff and in the manufacture of oxychloride cement. Magnesite is also used in chemical industry as source material for manufacture of magnesium compounds like magnesium sulphate (Epsom salt) and other salts used in paper and pharmaceutical industries. It is also used in textile, rubber, glass and ceramic.

14.3 BUILDING MATERIALS

India is gifted with huge resources of various types of building and monumental stones. Granite and marble are important due their aesthetic values and unique features. Apart from these other rocks are quartzite, sandstone, limestone, slate etc. Rock-based materials have been used in a variety of ways in the building industry for building construction, structural works and for making road and pavement. Building materials are hard, resistant, and tough that can withstand weathering and abrasion. The workability of building materials depends on their hardness and durability. In this subsection we will briefly discuss few building stones.

14.3.1 Granite

Granite is a plutonic felsic rock with quartz and feldspar as essential minerals. Granite in the form of building structural and ornamental stones has acquired important position in the field of modern architecture (Fig. 14.5). The word granite has been derived from Latin work '*Granum'* meaning grain. Besides hard and compact nature the texture of granite readily takes up good polish which gives it beautiful appearance. Colour varies from pink, grey, red and black with different textures. This has made it most opted building stone. Apart from 'true granite' commercially, available granite includes many types of igneous and metamorphic rocks namely dolerite, basalt, porphyry, syenite, diorite, gabbro, charnockite, khondalite, schist and gneiss. Highly priced black granite is actually gabbro or dolerite. The granite used in ornamentation and structural purposes must possess hardness and compactness apart from its pleasing appearance. The quality and use of granite depend upon its granularity, colour, presence of structural elements, inclusions, brittleness, chemical and mineralogical compositions, physicochemical properties and shape and size of blocks.

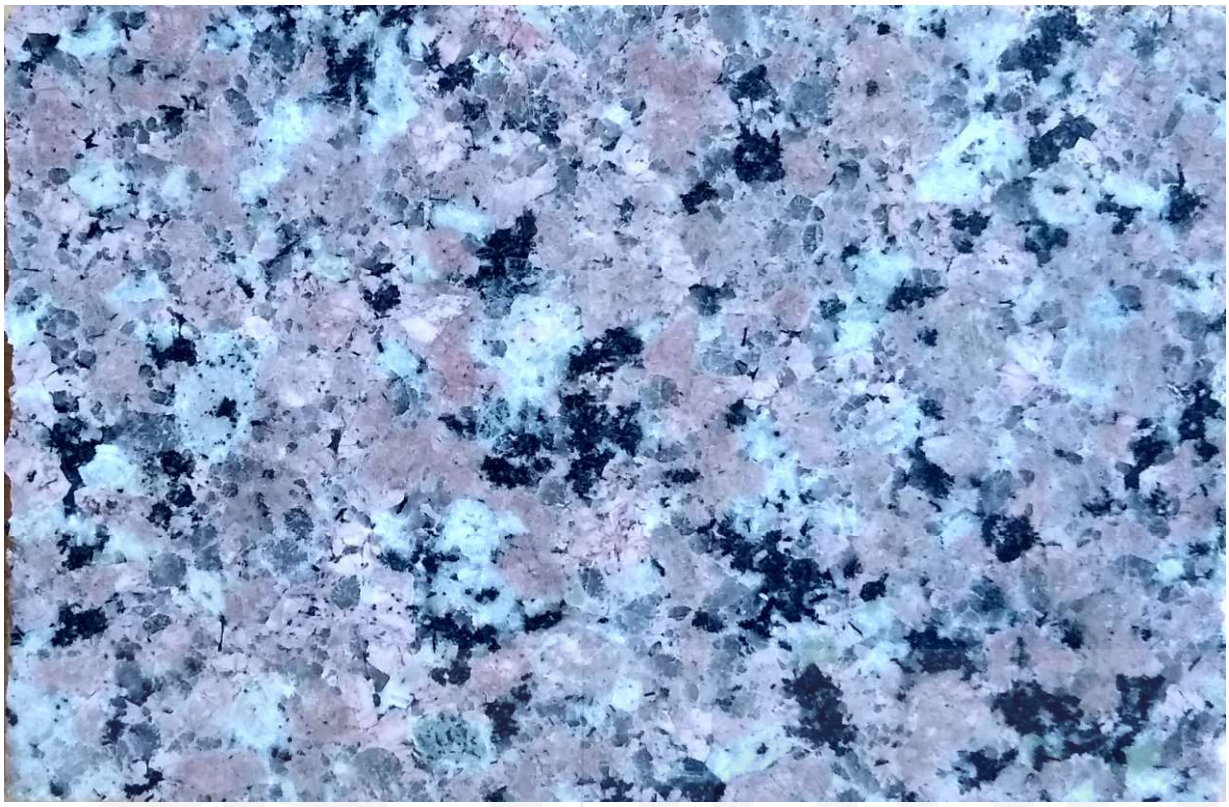

Fig. 14.5: Polished slab of granite.

Distribution: Granite occurs in almost all parts of India such as Anantpur, Chitoor, Guntur, Hyderabad, Warangal Districts in Andhra Pradesh; Bangalore, Bellary, Tumkur Districts in Karnataka; Ajmer, Alwar, Barmer, Bhilwara Districts in Rajasthan; Coimbatore, Dharampuri, Salem Districts in Tamil Nadu; Deogarh, Banka, Godda, Gumla, Hazaribag, Palamu, Ranchi and Singhbhum Districts in Jharkhand.

Uses: Granite is mainly used as construction material and road metal. The use of processed or polished granite is however, restricted and is employed in decorative purpose like exterior, interior wall panelling flooring wall, platforms for kitchen, sinks, table tops, monuments, name plates, flower vases.

14.3.2 Marble

Marble is a calcareous metamorphic rock. Marble is considered as one of the oldest building material used in monuments, decoration and building construction. The word 'marble' has been derived from Latin word '*Marmaros*' which means shining stone. Any stone capable of taking polish without any regard to its chemical composition was designated as marble in early days. Marble is a crystalline rock exhibiting sugary (saccharoidal) texture (Fig. 14.6) consisting mainly of calcite or more rarely dolomite. Marble is white in colour although due to impurities colour may vary. Often the individual grains are so small that they are not visible with naked eyes. Marble can also be coarse grained. The white Makrana marble commercial variety, referred to locally as 'Sang-eMarmar' (meaning pure white/ivory stone), contains ~ 100% white calcite grains. The crystalline granoblastic, interlocking and compact texture of marble makes it less porous which enhances its durability and resistance. These qualities have made the marble an ideal material for monuments and buildings from historical times. Marble is metamorphosed limestone.

Fig.14.6: Marble exhibiting crystalline sugary (saccharoidal) texture.

Uses: Marble is one of the best building materials used for flooring exterior and interiors of walls, monuments, architecture and other construction applications. Makrana marble is one of the most preferred ornamental and masonry stones from north-west India. It has been used in several spectacular heritage buildings and monuments within the country and abroad. Famous monuments like Taj Mahal of Agra (one of the Seven Wonders of the World and a UNESCO world heritage site), Lotus temple of Delhi, Victoria Memorial of Kolkata and are constructed of marble. White marble has been used in various structures within Red Fort (both in Delhi and in Agra), Humayun's Tomb and Akbar's Tomb. In abroad, Makrana marble has been used in Sheikh Zayed Mosque, Abu Dhabi, UAE, and Moti Masjid, Lahore, Pakistan.

Watch the following video to more about the formation of marble, skarn deposits and other industrial minerals.

- **Contact metasomatic and contact metamorphic deposits**

  Link: http://egyankosh.ac.in//handle/123456789/53458

14.3.3 Limestone

Limestone is a calcareous rock formed both organically and inorganically. India has plentiful deposits of limestone and is extensively used for building and construction purposes. It is a carbonate of lime or calcium. When magnesium replaces the calcium in part, it forms dolomitic limestone. It can be crystalline, pisolitic, oolitic or earthy. The impure limestone may be argillaceous, siliceous, ferruginous, bituminous or dolomitic in nature (Fig. 14.7). Nomenclature of limestone may vary based upon its colour, structure, locality and formation in which it occurs and its genesis etc. Limestone is a sedimentary rock having both marine and fresh water origin. Limestone occurs in the form of extensive beds, bands and pockets. Silica, iron, aluminium phosphorous, sulphur, manganese and carbonaceous matter are present as impurities. The content of calcium is product of weathering of rocks and is transported to the sedimentary basins in the form of bicarbonates, carbonates and sulphates. The calcium carbonate is deposited by inorganic, organic and mechanical processes. Carbon dioxide plays vital role in inorganic process.

Fig. 14.7: Dolomitic limestone of Sonbhadra District in Uttar Pradesh.

Distribution Limestone is widely distributed in many places such as Adilabad, Cuddapah, Guntur, Hyderabad, Karimnagar, Kurnool, West Godavari Districts in Andhra Pradesh; Belgaum, Chitradurga, Shimoga, Tumkur Districts in Karnataka; Karbi-Anglong, Lakhimpur, Nagaon Districts in Assam; Hazaribag, Palamau, Dhanbad Districts in Jharkhand; North Eastern part of Goa, Diu town, Malala and Nagao Districts in Goa; Amreli, Banaskantha, Bhavnagar, Bharauch Districts in Gujarat; Ambala, Bhiwani and Mahendragarh Districts in Haryana; Bilaspur, Chamba, Kangra, Shimla Districts in Himachal Pradesh; Sonbhadra District in Uttar Pradesh; Ajmer, Alwar, Banswara Chittaurgarh, Jaipur, Jaiselmer Districts in Rajasthan; Almora, Pithoragarh, Dehradun Districts in Uttarakhand; Anantnag, Baramula, Doda, Kathua Districts in Jammu & Kashmir. Limestone and dolomite deposits are located in Raigarh, Janjir-Champa, Bilaspur, Raipur, Durg and Rajnandgaon Districts.

Uses: Limestone is mined in India on very large scale. It is extensively used in cement industries, iron and steel, chemical, sugar and paper industries. Limestone is also used in fertiliser, ferro-alloys, glass manufacture, lime manufacture, foundry, refractories, textile, electrode, ceramic, sponge iron. Hard, siliceous, dolomitic and argillaceous limestone is used as dimension stone. Flaggy limestone of varying colours and fine texture is suitable for paving and flooring.

14.3.4 Quartzite and Sandstone

Sandstone is a sedimentary rock composed mainly of sand-sized (0.0625 to 2 mm) mineral particles or rock fragments (Fig. 14.8a). It contains the framework grains dominantly quartz or feldspar because they are the most resistant minerals to weathering processes at the Earth's surface. The framework grains are bound by matrix and cement. You will read about matrix and cement in block 3 of BGYCT-135 course. Quartzite is a metamorphic rock formed by metamorphism of sandstone. Pure quartzite is usually white to grey (Fig. 14.8b). It occurs in various shades of brown, pink and red due to varying amounts of iron oxide (Fe_2O_3). The presence of impurities gives yellow, green, blue or orange colour to quartzite. Quartzite and sandstone serve as building and road material.

(a)

(b)

Fig. 14.8: a) Sandstone in Sonbhadra District in Uttar Pradesh; Hand specimens of pure quartzite from IGNOU Headquarters, New Delhi.

Distribution: These are most common sedimentary rocks extensively distributed in different parts of the country. Their occurrences are mainly found in Kota, Bundi, Udaipur, Tonk, Ajmer Districts in Rajasthan; Hoshangabad District in Madhya Pradesh; Rohtas, Munger and Gaya Districts in Bihar; Mirzapur and Sonbhadra Districts in Uttar

Pradesh. The limestone and sandstone deposits of Vindhyan Supergroup are quarried in Son valley in Bihar and Uttar Pradesh; Rewa and Jabalpur Districts in Madhya Pradesh; Guntur and Bhima Districts in Andhra Pradesh. Vindhyan sandstones from Jodhpur District, Rajasthan, yield very good flagstones particularly suitable for fine carvings and are considered good for fabricating perforated and ventilating windows and screens, usually found in big palaces. Vindhyan sandstones of Bhander Group of uppermost Vindhyan age are known as excellent building stones, due to their regular bedded formation, uniform grain-size, soothing colours, high durability and easy workability. The stones are cream and light grey in colour with crimson and pinky tints. The famous Sanchi Stupa and stupas of Sarnath and Barhut are built of Vindhyan sandstones. The famous Fatehpur Sikri, built by Emperor Akbar, is entirely of pink Vindhyan sandstones. The Delhi Secretariat and Rashtrapati Bhawan of New Delhi are made of red sandstones. A major part of the sandstones are quarried in Rajasthan, particularly in Bundi, Kota, Dholpur, Jaipur, Bharatpur and Bikaner and also in Mirzapur and Sonbhadra Districts of U. P.

Watch the following video to more about sedimentary types of ore deposits.

- **Introduction to ore deposits**

  Link: http://egyankosh.ac.in//handle/123456789/53454

14.3.5 Slate

Slate is a low-grade metamorphic rock of argillaceous origin. It has fine grained texture and splits into thin layers. Slate occurs in varying colours grey to steel grey, brownish ash colour, pink, purple etc. It is used for roofing, pavements etc.

14.3.6 Lime, Clay and Sand

It is an important constituent for building and construction work. It is mainly prepared from limestone, dolomite and other calcareous material which when heated in kilns to around 900^0C quicklime is formed after removal of CO_2. It is an essential material for construction of buildings based upon size. Coarse sand is useful for concrete however fine sand is best suited for plastering the walls. The source of sand is mainly rivers. It is used in making bricks and cement. It occurs extensively in the country except in the rocky terrain.

In the previous sections we have studied about the industrial minerals and building materials. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 1

a) List the chief minerals of mica group.

b) Name three mica belts in India.

c) List four building materials.

d) Give five categories of gypsum.

e) Give three uses of limestone.

14.4 USAGE OF MINERALS IN INDUSTRIES

Now we will learn about minerals used in different industries in following sections.

Minerals are used in industries like refractory, fertiliser, ceramic and glass, chemical and pigments, abrasive and gemstone.

14.4.1 Refractory Industry

Refractory mineral is a heat-resistant material or in other words minerals which can withstand high temperature and are resistant to decomposition by heat, pressure, or chemical attack. Refractory minerals can sustain high temperature for example 1500^0C and above and can be moulded into bricks. They are used for various purposes, the most important use being in the linings of furnaces for smelting and refining metals. They are also used for lining incinerators, kilns in ceramic industry and in glass and cement manufacture, for coke. They are used in gas or electric plants. They also find use in spark plugs for automobiles. In India in recent years the use and geology of refractories has acquired special significance with the tremendous growth in metallurgical plants. Refractory minerals include fireclay, graphite, dolomite, magnesite, chromite, bauxite, sillimanite, kyanite group of minerals, quartzite and quartz-schist, diaspore and zircon etc.

Let us discuss few minerals considered as refractory mineral.

Asbestos is amphibole of fibrous nature, consisting of long, fine flexible, soft and silky fibers. These fibres can be spun readily into threads and woven into cloth. The utility of asbestos relies upon its property of being spun into yarn and its resistance to heat due to its fibrous tendency. Asbestos is an excellent non-conductor of heat and electricity. Asbestos is utilised in break-lining and clutch facings, gaskets, boilers covering, manufacture of cement, sheets, boards, paper, pipe, roofing tiles, fire proof paints, insulation.

Fire Clay is high-alumina clays with some non-plastic refractory flint and moderately refractory plastic clays. It can withstand temperature rise of 2714^oF to 2984^oF. Fireclays occur mainly as underlying the coal seams. Fireclay deposits are found in Jharia and Raniganj coal fields of Jharkhand and West Bengal, Korba coalfields of Madhya Pradesh and Neyveli lignite field of Tamil Nadu. Fire clay is chiefly consumed in refractory industry. Several kinds of fireclay bricks are manufactured by admixing with calcined bauxite or kyanite in suitable proportion to meet the different insulation requirements. Bricks are used in iron and steel, ferro alloys, cement, foundries and glass.

Graphite is allotropic form of pure carbon, chemically similar to diamond and wood charcoal. The word '*graphein*' means write. It occurs in three forms, such as: 1) flakes, 2) dusts, and 3) lumps. It is mainly found in metamorphic rocks like gneisses, schist, marble, quartzite and altered coal beds. It occurs in igneous rocks, veins and pegmatites. The graphite deposits occur in Jharkhand and Odisha. It has a metallic lustre and feels cold like metal, when handled. Owing to its being a good conductor of heat. Graphite occurs in two forms: Natural graphite which includes (a) crystalline and (b) amorphous varieties, and artificial/manufactured graphite. The inherent qualities of graphite, for which it is so much in demand in the manufacturing industries, are its high lubricity, refractoriness or ability to withstand high temperature, good electrical and heat

conductivity, and resistance to reaction with ordinary chemical reagents. Thus, flaky graphite is used in the manufacture of crucibles for melting metals. It is also used in the manufacture of lead pencil, batteries, lubricants and brushes. It is also used in atomic reactors. The commercial graphite is graded mainly on its carbon content.

Dolomite is known for its double carbonate of calcium and magnesium ($CaCO_3$= 54.35% and $MgCO_3$= 45.65 %). When magnesium of dolomite is replaced by iron or manganese and with lesser proportion of magnesium carbonate, it is known as dolomitic limestone. Dolomites are not known to form through epigenetic replacement of limestone. The process of dolomitisation is related to joints and fissures through which the solutions penetrated and thick beds of limestone may be changed to dolomite. Dolomite is widespread in all parts of the country. The deposits are found in Anantpur District of Andhra Pradesh; Palamau District of Jharkhand; Mahendragarh District of Haryana. All grades dolomite are found in Balaghat, Bastar, Bilaspur, Chindwara Districts of Madhya Pradesh; Chandrapur, Nagpur and Yeotmal Districts of Maharashtra; Koraput, Keonjhar, Sambalpur and Sundargarh Districts of Odisha; Ajmer, Bhilwara, Alwar Districts of Rajasthan. Dolomite finds its use in multiple fields such as a flux, as refractory material of iron and steel industry. It is also utilised in building materials, glass, ferro alloys, alloy steel, chemicals and soft abrasives.

14.4.2 Fertiliser Industry

Fertiliser minerals plays vital role to enhance food production. Three principal elements are necessary for plant growth and high crop yield. These are nitrogen, phosphorous and potassium. Natural nitrates have been widely replaced by nitrogenous fertilisers made from atmospheric nitrogen. Phosphatic fertilisers, earlier produced from bones of dead animals, are now processed from phosphate rocks using sulfuric acid to produce soluble superphosphate. Potassium fertilisers are at places extracted from evaporate deposits. The natural phosphates of importance are apatite which also a phosphate of calcium with minor content of chlorine and fluorine and rock phosphates like phosphorites, phosphatic limestone, guano, basic slag etc. The phosphatic rocks occur in varied form and may be fragmental, pelletal, nodular, oolitic, pisolitic, lenticular, platy, granular and massive in form. They may occur as marine sedimentary beds, phosphatic marls and limestone beds reworked pebbles, residual concentration of phosphatic materials and apatite deposits. Apart from their use in fertiliser industry the phosphates are also used in manufacture of elemental phosphorous, chemicals, glass, sugar and iron and steel industries. Phosphates also find its utilisation in the manufacture of safety matches, medicines, soft drinks, baking powder, photography, cement and ceramics.

Calcium is also an important element required for plant life. It may be supplied by lime, limestone, marl, oyster shells, or gypsum. Calcium being soluble in surface water it is leached out and the soil becomes deficient in lime and becomes acidic. Soil is neutralised by adding lie to it. Besides correcting the soil acidity, the lime granulates heavy clay soil, provides plant food, promotes digestion of other fertilisers and counteracts some soil poisons. Calcareous rocks occur in all the principal geological formations of India, right from the Precambrian to Recent.

Potassium is essential for plants. Potassium minerals of economic importance other than silicates occur as chlorides, sulphates and nitrates. The mineral glauconite is a hydrous silicate of iron and potassium and forms a potential source of potash. Potash salts are used in fertiliser industry. Other minerals used as fertilisers, include gypsum, sulphur and borax.

14.4.3 Ceramic and Glass Industry

Clay is the vital raw material to be used in ceramic industry. Feldspar is used both in the body and glaze for chinaware. The constituent mineral which is less than 0.002 mm or so and they can be identified only by the help of electron microscope, X-ray and thermal analyses curves. Examples of clay minerals are kaolinite, montmorillonite, illite and smectite. Clay is an aggregate of minerals and colloidal substances which become plastic when wet and harden when subjected to high temperatures. Plasticity, shrinkage, fusibility are important physical properties of clay upon which its various uses are dependent. Clay has diverse uses, e.g. ceramics, cement, refractory, paper and textile, rubber, cosmetic, pharmaceutical, insecticide, electrical and building industry. Amongst the minerals of feldspar group, alkali feldspar is mainly utilised in the manufacture of ceramics, glass, pottery, vitrified enamels, porclain and glasswares. Wollastonite ($CaO.SiO_2$) is an important ceramic mineral because of its low thermal expansion, it finds major use in ceramic industry.

Quartz and silica-sand are chief glass manufacturing materials. They are mixed with sodium carbonate or sodium sulphate in a prescribed proportion for easy manufacture of glass. Calcium in the form of lime or limestone is added to give strength to glass. Addition of borax provides transparency to glass whereas manganese dioxide, nickel oxide, cobalt and chromium are meant for providing different colours to glass. Coal is utilised for fire purpose. Quartz and silica sand are used in glass, foundry, ferro-silicon alloy and cement industries besides being used in many other industries like ceramic, fertiliser, alloy steel, abrasive, chemical, coal washery, paint, rubber, textile etc.

14.4.4 Chemical and Pigment Industry

A number of minerals are used as chemical in a raw state or in the form of ingredients just like rock salt which compositionally is rock salt, borax, fluorspar etc. Rock salt (NaCl) is the solid salt deposit, consisting mainly of sodium chloride with minor amounts of calcium sulphate, calcium chloride, magnesium chloride. It is most important raw material used in chemical industry in manufacture of minerals like caustic soda, soda ash, chloride, hydrochloric acid and sodium metal. Rock salt is used in manufacturing dye, emulsions, tanning, food and wood preservative, cement, glass making, water purification, cotton and paper bleaching, refrigeration and medicines. Rock salt is also employed in metallurgical industries for treating, smelting and refining of ores and metals, in ceramics for glazes and in agriculture for cattle food, fertiliser and hay preservation.

Borax is a hydrated sodium borate and is important chemical mineral. It is used as good cleaner. It is an important component used in the manufacturing of baking powder, food preservatives, ceramic and glass manufacturing, abrasive, refractory, paint, rubber, sugar, pharmaceuticals cosmetics, paper and textile. **Fluorite** or Flurospar is compositionally CaF_2. It is vital chemical mineral because of its fluorite content Aluminum fluoride and cryolite are the most important compounds generated from fluorite. This mineral also holds important position because of its vast use in metallurgical industries. Fluorite s used in fluxing agent in iron and steel, ferro alloys industries. It is also used in foundry, electrode, glass industry and ceramics.

Natural mineral pigments consist mainly of **limonite** or **hematite** with or without mixture of clay and manganese oxide. **Ochre** is a mixture of hematite, limonite and clay with 15-20% iron oxide and provide yellowish and brown colours. Ochre is found in various colours like yellow, red, brown and white. It is natural pigment mineral. Pigments can be extracted by direct treatment an roasting of minerals. **Umber** is brown ochre with proportions of manganese and limonite.

14.4.5 Abrasive Industry

Abrasive minerals are used in cutting, crushing, abrading and polishing. They are of two types, natural or mineral and artificial abrasives. The capability of the material to cut, crush, grind, scour and polish is dependent upon its hardness. This is the essential property of an abrasive. The industrial diamonds namely carbonado, a black, hard diamond which is used in diamond drill bits and tools It is used in boring metals and abrasive wheels etc whereas bort which is opaque or slightly translucent crystal fragment is used in the manufacture of aeroplane and motor car engines for boring and abrasion of surfaces. Corundum is aluminium mineral having composition Al_2O_3 and is hardest mineral next to diamond**.** The corundum is used in abrasive. Garnet is used as abrasive mineral. The almandine (Fe-Al garnet), of garnet group is mainly used as an abrasive due its hardness, toughness. It is used as loose grains and finely ground powder for glass and optical lens grinding and surfacing ornamental stones and in paper cloth for rubbing hardwood, automobile bodies, copper and brass, removing paints and varnishes, finishing hard rubber, leather, felt and silk hats.

In the previous sections we have studied about the minerals used in refractory, abrasive, ceramic and glass manufacturing and fertiliser industries. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 2

a) What are refractory minerals?

b) What are the uses of graphite?

c) List three minerals used in fertiliser industry.

d) List four clay minerals.

e) What is abrasive mineral?

14.4.6 Gemstone Industry

Beauty, rarity and durability are main virtues of a gemstone. They must possess certain properties such as hardness to resist mechanical and chemical actions. The term ‘gem’ is attributed to cut stones whereas the uncut stones are termed as ‘gemstones’. The characteristic properties of gems are shine, opalescence, iridescence and dichroism and based upon these gemstones are grouped into:

- precious stones such as diamond, emerald, sapphire, ruby, opal and pearl
- semi-precious stones which include aquamarine, moon stone and amethyst

Gemstones mainly occur in igneous rocks, granitic pegmatites and as detrital grains in alluvial sediments. They occur as veins, in cavities, in volcanic pipes and in variety of ways. Sapphire and pyrope occur in some of the diamondiferous kimberlites. Usually potash rich or soda lithium rich pegmatites are the host rocks of many beautiful gemstones, such as, topaz, sapphire, ruby and zircon. Gems are also found in basic and andesitic lava flows, and granite intrusives. Although metamorphic rocks are generally barren of gemstones, some contact metamorphic limestones may contain lapis lazuli and ruby. Opal is deposited from magmatic fluids while amethyst develops in vein deposits. Turquoise is a gemstone of supergene origin. Almost all gem stones are found in stream gravels, due to their highly resistant and chemically inert character Gemstones have very significant role in jewellery, however, semi-precious stones apart from jewellery are used as ornamental stones for wall decoration, floors of building, vases etc.

Let us discuss about daimond.

Diamond was found in 800 BC and is the hardest substance known. When properly faceted, light falling on the stone undergoes total internal reflection giving it the dazzling brilliance. Major part of diamond recovered from the rocks is of the industrial variety, known as bort and carbonado etc. based on their physical attributes. Only a minor part of diamond produced is of the gemstone variety. Primary sources of diamonds are kimberlite pipes and vents, and lamproite, or peridotite dykes. Secondary source is in conglomerate beds, alluvial gravels and sand. The kimberlites are dense, and dark coloured ultrabasic rocks, rich in magnesium, containing olivine, enstatite-bronzite, chrome diopside phlogopite, and pyrope garnet with minor amount of ilmenite and perovskite. However the placer type diamond deposits are mainly derived from the destruction and reworking of primary diamond bearing rocks by various surface processes. Depending upon the mode of their formation these have been classified into alluvial, sea beach, aeolian type of origin. Diamond deposits may be classified into three types based upon their geological settings such as kimberlite, conglomerate and alluvial gravels. Diamond bearing localities are Wajrakarur pipes, Andhra Pradesh and Panna belt, Madhya Pradesh.

Watch the following video to more about magmatic processes responsible for formation of diamond.

- **Late magmatic deposits**

  Link: http://egyankosh.ac.in//handle/123456789/53454

14.5 SUMMARY

In this unit we had discussed about the non-metal minerals used as industrial mineral and building material. We also learnt about non-metallic minerals utilised in refractory, abrasive, fertiliser, chemical and paint, ceramic and glass manufacturing industries. Let us summarise what we have learnt:

- Industrial minerals and rocks are utilised because of their important physical and chemical properties either as raw materials or after processing. These properties remain essentially unchanged in the end use after processing
- Chief minerals of mica are muscovite, biotite, lepidolite, phlogopite. Mica forms from late magmatic solutions in the pegmatites.

- Gypsum is required for cement and fertiliser industry. Magnesite is used as soft abrasive and refractory mineral.
- Granite, marble, limestone, sandstone and quartzite are used as building materials.
- Refractory minerals include fireclay, graphite, dolomite, magnesite, chromite, bauxite, sillimanite, kyanite group of minerals, quartzite and quartz-schist, diaspore and zircon etc.
- Clay minerals, feldspars, quartz and silica sand are used in ceramic and glass manufacturing industry.
- Rock salt is most important raw material used in chemical industry in manufacture of minerals like caustic soda, soda ash, chloride, hydrochloric acid and sodium metal.
- Abrasive minerals are used in cutting, crushing, abrading and polishing and are of two types, natural or mineral and artificial abrasives-for example garnet
- Gemstones can be grouped into precious stones (diamond, emerald, sapphire, ruby, opal and pearl) and semi-precious stones (aquamarine, moon stone and amethyst).

14.6 ACTIVITY

Make a list of non-metallic mineral deposits occurring in the state of your residence.

14.7 TERMINAL QUESTIONS

1. Discuss the mode of occurrence, distribution and uses of gypsum.
2. Describe the distribution and uses of limestone and marble.
3. Give an account of refractory minerals.
4. Discuss about minerals used in fertiliser industry.
5. Write about minerals used in ceramic and glass manufacturing industries.

Audio/video material based questions

- List the non-metallic ore deposits formed due to contact metasomatism.
- Mention about the processes responsible for formation of limestone and sandstone.
- Which magmatic concentration process forms the diamond deposit?

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14.10 ANSWERS

Self Assessment Questions

1 a) Please refer the table 14.1.

b) Andhra Pradesh mica belt, Bihar mica belt and Rajasthan mica belt.

c) Granite, marble, limestone, quartzite

d) Rock gypsum, gypsite, alabaster, satin spar and selenite.

e) Cement industries, iron and steel, chemical and paper industries.

2 a) Refractory mineral is a heat-resistant material or in other words minerals which can withstand high temperature and are resistant to decomposition by heat, pressure, or chemical attack.

b) Graphite is used in lead pencils, batteries, lubricants and electrical industries.

c) Phosphorites, limestone, glauconite.

d) Kaolinite, montmorillonite, illite and smectite.

e) Abrasive is the material possessing the capabilities to cut, crush, grind, scour and polish the surface.

Terminal Questions

1. Please refer to subsection 14.2.2.
2. Please refer to subsection 14.3.3 and 14.3.2.
3. Please refer to subsection 14.4.
4. Please refer to subsection 14.5.
5. Please refer to subsection 14.6.

UNIT 15

COAL AND PETROLEUM

Structure

15.1 INTRODUCTION

In the previous units you have studied about concept of ore and ore deposits, gangue minerals, processes of ore formation, important metallic minerals and industrial minerals and building materials.

Coal and petroleum are fossil fuels which have been widely used as source of energy since the time of industrial revolution. Although, there are many different types of fuels, among which the two major types of fossil fuels are coal and petroleum. They were formed many hundreds of millions of years ago. They are derived from the ancient organic remains and hence known as fossil fuels. Coal meets a large part of our energy needs and plays a very important role in the mineral industry. Petroleum is the key fuel of modern times and is of immense value in the development of a country. In this unit, we will discuss about origin, occurrence and distribution of coal and petroleum in India.

Expected Learning Outcomes

After reading this unit you should be able to:

- ❖ define coal and petroleum;
- ❖ describe the varieties, origin, and ranks of coal;
- ❖ discuss origin, formation and mode of occurrence of petroleum; and
- ❖ recognise Indian occurrences of coal and petroleum.

15.2 COAL

Coal is one of the principal fossil fuels and is a primary source of energy and power. The term coal is generally applied to a sedimentary formation of highly carbonaceous in nature and is formed by the accumulation of previously existing plant material. Coal cannot be defined as a mineral because it is not homogenous and is not of inorganic origin. It is considered as rock as it is a solid substance forming one of the units of the Earth's crust. Coal may be defined as plant debris that has experienced significant changes in the physical properties and chemical composition due to various biochemical and geological processes.

Some coal varieties are very rich in volatile matter. Such high volatile coal on heating in ambient air is converted into **coke**. Coke is a compact form of impure carbon obtained by heating in total absence of air. Coke is mainly used for smelting metals, boiler installations, etc. It is used in the manufacture of steel and in the extraction of many metals. The quality of coal depends on its carbon and ash content, coking properties, gas yield, crushing strength, size of particles, etc. Coal is used as a source of heat in a variety of ways. Throughout human history, coal has been used as an energy resource, primarily burned for the production of electricity and heat. It is one of the most essential raw materials in the extraction of metals. It is also used for industrial purposes, such as refining metals. Thermal power stations depend upon coal. Coal is the largest source of energy for the generation of electricity worldwide. Now, let us discuss about constitution of coal, varieties and rank, grade, origin of coal and some Indian occurrences.

15.2.1 Constitution of Coal

Coal is not homogenous substance; it is composed of a number of bands.

A) **Macroscopic Unit of Coal**

The coal bands are classified into four types, namely, vitrain, clarain, durain, and fusain. These components of coal can be studied in naked eye.

- **Vitrain** is the brightest portion or band of a coal and usually it occurs as a thin band. It is jet black in colour with a brilliant lustre and breaks with a conchoidal fracture.
- **Clarain** is less bright than vitrain and it occurs in bands of variable thickness. It has bright colour and silky lustre and does not show conchoidal fracture.
- **Durain** is the typically dull coal and occurs as thick bands. It is hard, grayish black in colour and breaks with irregular surface. It shows lustureless rough irregular fracture.

- **Fusain** resembles charcoal, so it is also called as mineral of charcoal. Fusain is black in colour, powdery in nature, occurs as patches and wedges and shows fibrous structure. It is more friable than clarain. Fusain is distinguished by its woody fibrous tissues when seen under microscope.

B) **Microscopic Unit of Coal:**

The coal constituents may be distinguished into number of units under the microscope, which are called macerals. In the same way as inorganic rocks are composed of minerals. For example granite rock is made up of feldspar, quartz and mica, where as coal consist of macerals. But, a mineral is identified by a well-defined chemical composition and its form and habit which are mostly crystalline. Whereas, maceral of coal varies widely in its chemical composition and physical properties and is not crystalline. All macerals are classified into three main groups: vitrinite, exinite (or loptinite) and inertinite

- **Vitrinite:** This is the most frequent and, important maceral group, occurring in bituminous coals. Vitrinites are the remains of humic plant substances, primarily lignin and cellulose. A polished coal sample exhibits a more or less clear structure of the woody tissues. The colour and reflectance of vitrinite changes progressively with rank.
- **Exinite (or Liptinite):** They are distinguished from the vitrinite by higher hydrogen content. Exinite are the remains of hydrogen-rich plant materials such as cutins, resins, fats, waxes, and sporopollenin (the outer cell walls of spores and pollen). Macerals of this group have brown red distinctive morphology and colour varies a lot. It may be golden yellow, red, orange and even of the same colour as the associated vitinite.
- **Inertinite:** In most cases consist of the same original plant material as vitrinite, but have been oxidised prior to coalification i.e. supposed to be inert during carbonization reaction. Inertinites can also include fungal bodies. Characteristic optical property of inertinite macerals is their high reflectance.

C) **Chemical Composition of Coal**

Chemically, coal is composed of various proportions of carbon, oxygen and hydrogen with small amounts of nitrogen and sulphur. Carbon is the major component (Table 15.1) of coal. Besides these, coals may contain varying proportion of mineral matter. Chemical composition of coal is determined by proximate and ultimate or elemental analysis. By proximate analysis, the moisture, volatile matter content, ash content (non-combustible mineral matter that remains after burning), fixed carbon and calorific value can be determined. Ultimate or elemental analysis includes the quantitative determination of carbon, hydrogen, nitrogen, sulphur and oxygen within the coal.

Table 15.1: Carbon content in coal.

Coal Types	Carbon percentage (%)
Peat	<40
Lignite	40-55
Bituminous	40-80
Anthracite	80-95

15.2.2 Varieties and Ranks of Coal

According to the nature of the original plant material from which coal have been formed, it may be divided into two types- Humic coals (woody coals) or humulites and sapropelic coals (non-woody coals) or sapropelites. The humic coals are mainly formed by the wood and bark of land and swampy plants. The sapropelic coals are derived from non-woody matter like leaves, spores, cuticles etc. of plants as well as from organic oozes, algae, fungi and other minute floating planktons.

The process of the transformation of the plant material into coal may be complete or may be arrested at any one stage, thus giving rise to coals of varying maturity. This is termed as **rank of coal**. The transformation of vegetable matter into coal is brought about in two stages:

(i) Peat-forming (or biochemical) stage: This process is called **humification process**.

(ii) Geochemical stage: It is the conversion of peat into higher ranks of coal. This process is called **coalification process**.

The percentage of carbon, hydrogen, volatiles and moisture contents determine the rank of coal. Based on the rank of the coal, that defines degree of transformation of wood into coal through the natural processes of deposition, compaction and biochemical changes.

Coal is divided into four major classes in order of progressive maturity:

- **Peat**
- **Lignite**
- **Bituminous, and**
- **Anthracite** (Fig. 15.1)

The rank of coal from Peat to Anthracite shows a gradual increase of carbon content and decrease in volatiles, oxygen, hydrogen and water.

(i) **Peat:** It is the first stage in the formation of all coal types. It is an accumulation of partly decomposed and distinguished organic materials derived mainly from woody parts of plants. Its colour varies from light brown to dark brown. It varies in consistency from a fibrous, matted, porous, turf-like material to a soft, plastic mud type coal (Fig. 15.1a).

Distribution: The important sources of peat in the country are in the Nilgiri hills of Tamil Nadu and the Sundarbans of West Bengal.

Uses: Peat is a low value fuel in its application. It finds uses where available in abundance as domestic fuel, gas purifier, for steam raising, in thermal power stations and also as a soil treatment material.

(ii) **Lignite:** It is the next stage in the formation of coal from peat. It is an immature coal. It is sometimes called 'brown coal' because of its characteristic brown colour. It is compact and earthy in texture and contains impressions and remains of woody matter and leaves (Fig. 15.1b).

Distribution: In India lignite occurs in Neyveli area, South Arcot District, Tamil Nadu and at a number of places in Pondicherry, Palana area in Rajasthan, Kutch in Gujarat and Jammu and Kashmir, etc.

Uses: Lignite is used as domestic fuel and also in industry for distillation and gasification. This variety of coal has also been used in steam locomotives and for producing gas.

(iii) **Bituminous:** It is also known as common coal and is the important variety of commercial coals. Bituminous coals are brittle, dense, dark in colour, well jointed and often show well-defined bands of bright and dull materials (Fig. 15.1c). They are compact in structure and usually break into prismatic and cubical blocks when struck with hammer. This coal does not disintegrate when exposed to air. They burn with a yellow smoky flame. On the basis of its carbon content, common bituminous coals are of three types:

- sub-bituminous,
- bituminous
- semi-bituminous.

Distribution: In India, bituminous coals are found in Lower Gondwana, Raniganj and Jharia Coalfields.

Uses: Usually they are used in the manufacture of metallurgical coke. Bituminous coals are used as fuel in stream raising, heating and producing gas besides in making of coke.

(iv) **Anthracite:** It is a coal of highest rank in which organic source has been completely transformed into carbonaceous substance. It is very hard and jet black in colour and compact in structure (Fig. 15.1d). Anthracite is very rare in India. Graphite is a crystalline form of the element carbon with its atoms arranged in hexagonal structure under high pressures and temperatures it converts to diamond (Fig. 15.2).

Distribution: Semi anthracite is developed in some parts of the Jammu and Kashmir and along the Northern and Eastern Himalayan region.

Uses: Anthracite is a favourite domestic fuel in regions wherever it is available. It is also used for steam rising and other heating purposes. However, it is not suitable for making coke due to its low volatile matter content.

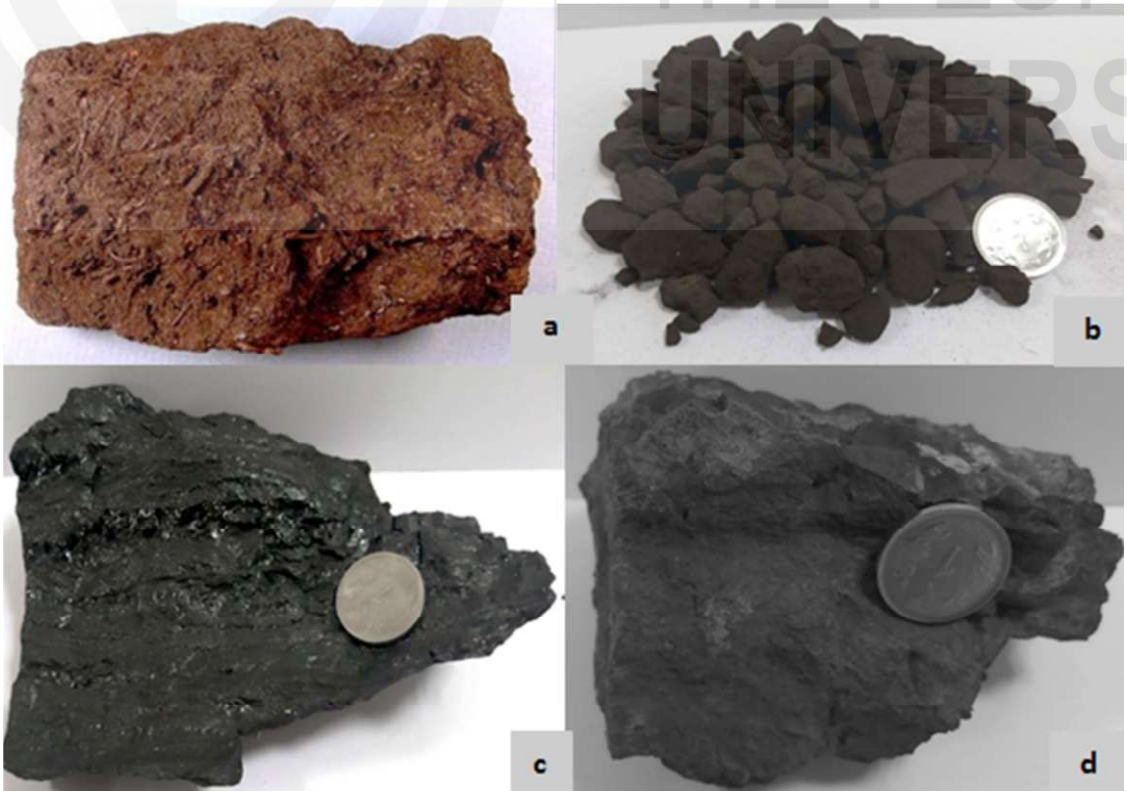

Fig.15.1: a) Peat (Source: https://www.pmfias.com/coal-formation)**; b) Lignite; c) Bituminous; and d) Anthracite coal.**

Fig.15.2: Graphite.

15.2.3 Grade of coal

The grade is the measure of quality of coal, and is expressed as its heating value. The heating value depends on the ratio of carbon to the other non-combustible matters present in the coal. Thus, the more the amount of carbon in coal the better is the grade. Grade of the coal is calculated in an ascending order of carbon content i.e.

Lignite →Sub-bituminous coal →Bituminous coal→Anthracite

The grade of non-coking coal is based on Useful Heat Value (UHV).The grade of the coking coal is based on ash content. Semi coking / weakly coking coal is based on ash plus moisture content. Based on the ash percentage, the coking coal can be divided into various grades. Useful Heat Value (UHV) is the amount of heat released during the combustion of a specified amount of it. These grades are (Table 15.2):

Table 15.2: Grades of Coking Coal. (Source: http://coal.nic.in/content/coal-grades)

Grade	Ash Content
Steel Grade- I	Not exceeding 15%
Steel Grade- II	Exceeding 15% but not exceeding 18%
Washery Grade- I	Exceeding 18% but not exceeding 21%
Washery Grade- II	Exceeding 21% but not exceeding 24%
Washery Grade- III	Exceeding 24% but not exceeding 28%
Washery Grade- IV	Exceeding 28% but not exceeding 35%

15.2.4 Origin of Coal

Coal originated as a result of long burial of vegetable matter formed by decay of plant material under a thick cover of sediments. Coal deposits have been formed both in fresh water and in brackish water. There exist different views regarding the mode of accumulation of plant material which ultimately gave rise to coal seams. According to one view, the coal forming materials was deposited and transformed where it grew, this theory is known as the **insitu theory**. Another view is that the plant material has been

transported and deposited in suitable places to form coal, this theory is known as the **drift theory**. Millions of years ago coals formed when the earth was covered with huge swampy forests where plants grew. Over time as the plants grew, some of them died and fell into the swamp waters. New plants grew up to take their place and then these died and the process continued. Over a period of time, there formed thick layers of dead plants decaying in the swamp. The surface and climate of the earth changed and water and dirt washed in, stopping the decaying process. After millions of years many plant layers had formed, one above other. The weight of the top layers and the water and dirt packed down the lower layers of plant matter. Under heat and pressure these plants produced chemical and physical changes in the plant layers which forced out oxygen and rich carbon deposits are left. Over a period of time, thus the material once had been plants became coal (Fig.15.3).

Watch the following video to know more about sedimentary ore deposits wherein coal has been discussed.

- **Introduction to ore deposits**

  Link: http://egyankosh.ac.in//handle/123456789/53454

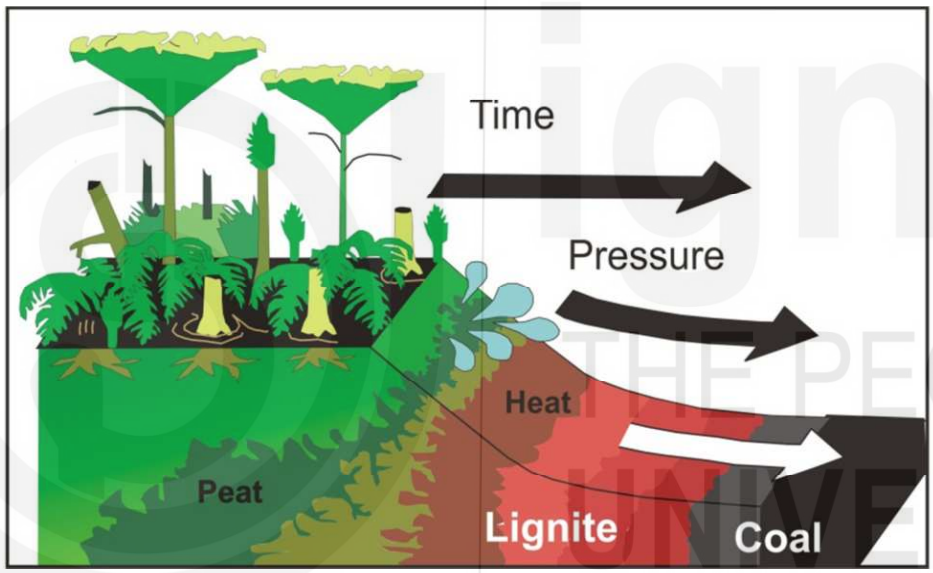

Fig. 15.3: Schematic diagram showing formation of coal.

All the available evidences stated that the major coalfields of the world have originated either in swamps or in brackish or fresh water basins, starting with abundant plant material, which might have grown in-situ in swamps or have drifted into these basins. This transport or drift might have been caused by any one or more of the natural agents- running water and ice, wind etc.

Coal occurs as a sedimentary rock in association with the sandstone, carbonaceous shale and occasionally fire clay in a regular succession and with repetitions. Igneous intrusions in the forms of dykes and sills are present in coal seams. The thickness of the coal seams varies from a fraction of inch to >100 feet.

15.2.5 Indian Occurrences

India is one of the five major producers of coal in the world. It is endowed with huge reserves of common or bituminous coal, chiefly of non-coking types. Major coalfields of country are situated in Damodar, Mahanadi, Godavari and Son-Narmada valleys. On the basis of their occurrence relative to geological age, coal deposits of India are classified into two groups: Gondwana Coals (Fig. 15.4) and Tertiary Coals (Fig. 15.6).

(i) **Gondwana Coals:** About 98 percent of coal annually produced in India comes from formations of the Lower Gondwana sequence (200 million years old) of the Permian age. The Lower Gondwana coals are mainly of bituminous type. The major coalfields occur in Jharkhand, West Bengal, Odisha, Maharashtra and Madhya Pradesh. These are:

- **Jharia Coalfield of Jharkhand:** The coalfield is located in Dhanbad District of Jharkhand and is regarded as the most important coalfields of India. They supply about 50 percent of the total Indian production of coking coal. Coals are low in moisture, sulphur and phosphorus, low volatile content and high fixed carbon and high calorific value.
- **Bokaro Coafield of Jharkhand:** The coalfield spreads about 65 km from east to west and 10 to 16 km from north to south of Bokaro District of Jharkhand. They contain some of the thickest coal seams. Coals are of bituminous, coking coal type.
- **Raniganj Coalfields of West Bengal and Jharkhand:** One of the largest coalfields of the country. Most of the coalfields are in the Raniganj area in Burdwan district in West Bengal. They extend to adjoining areas of Jharkhand. It is situated about 185km NW of Kolkata. These coalfields are spread over an area of 1550sq.km. Coals are of bituminous, high moisture and high volatile content. Raniganj Coalfield is the major producer of superior quality non-coking coal.

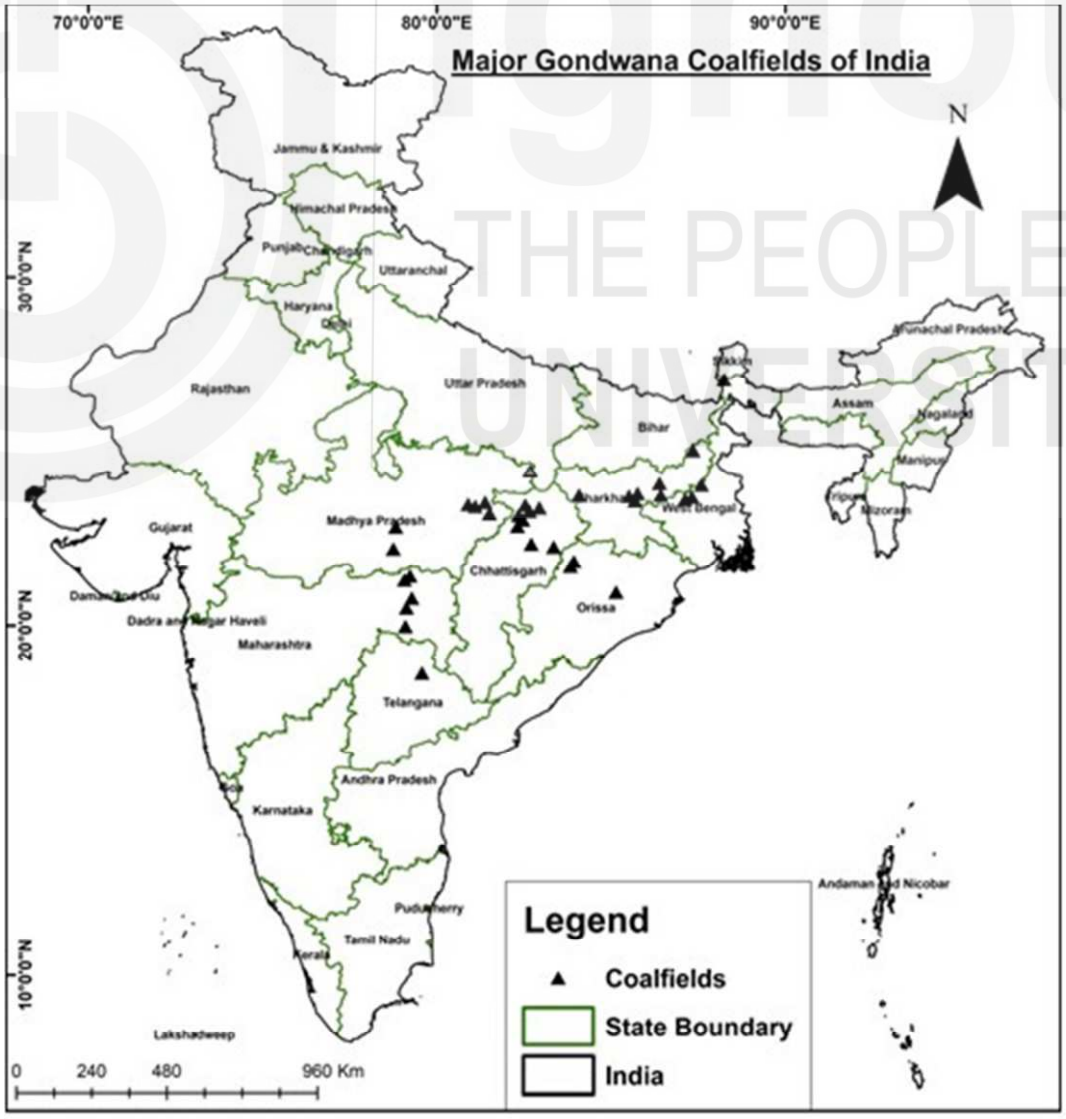

Fig. 15.4: Map showing major Gondwana Coalfields of India. (Prepared by Rohit Kumar)

- **Singrauli Coalfield:** It is one of the most important coalfields of Madhya Pradesh. This coalfield lies partly in Madhya Pradesh and partly in Chhattisgarh mostly in the basin of the Son River. It is spread over an area of 2002 sq. km., containing five coal seams. The products of these seams vary from non-coking high grade coals to moisture rich inferior grade coals. They are generally high moisture and high ash coals.
- **Talcher Coalfield of Odisha:** This is the most important coalfield of Odisha and is located in Angul District of Odisha. It is spread over an area of more than 500 sq.km (Fig. 15.5). Talcher Coalfield is subdivided into five productive areas. The quality of coal is low-grade non-coking.
- **Rajmahal Coalfield:** The coalfield is located in Jharkhand. It is situated along the western side of the Rajmahal Hills in the north to Birbhum District of West Bengal in the south.
- **Wardha Valley Coalfield** is located in Wardha Valley of Maharashtra.

Fig. 15.5: Open cast mining at Lakhanpur coal field of Jharsuguda, Odisha. (Photo credit: Premasil Patra)

(ii) **Tertiary Coals:** These coals are found in the states of Assam, Meghalaya, Nagaland, Arunachal Pradesh, Himachal Pradesh, West Bengal, Rajasthan, Kerala and Jammu and Kashmir (Fig.15.6).Tamil Nadu and the Union Territory of Pondicherry also have Tertiary coal reserves. Tertiary coals generally have low carbon and high percentage of moisture and sulphur.

Tertiary coals of Assam are spread in Makum, Nazira, Mikir Hills, Dilli-Jeypore and Lakhuni. Assam coal contains very low ash and sulphur content is high with high coking qualities. As a result of which these coal is not suitable for metallurgical purposes. Makum coalfield in Tinsukia district is the most developed field (Fig. 15.7). In Meghalaya, coal deposits occupy in the areas of Khasi Jaintia and Mikir hills. Tertiary coal of Jammu and Kashmir are spread in Kalakot and surrounding regions in Jammu, and south of Pir Panjal. In Himachal Pradesh, coal are found in Chamba district.

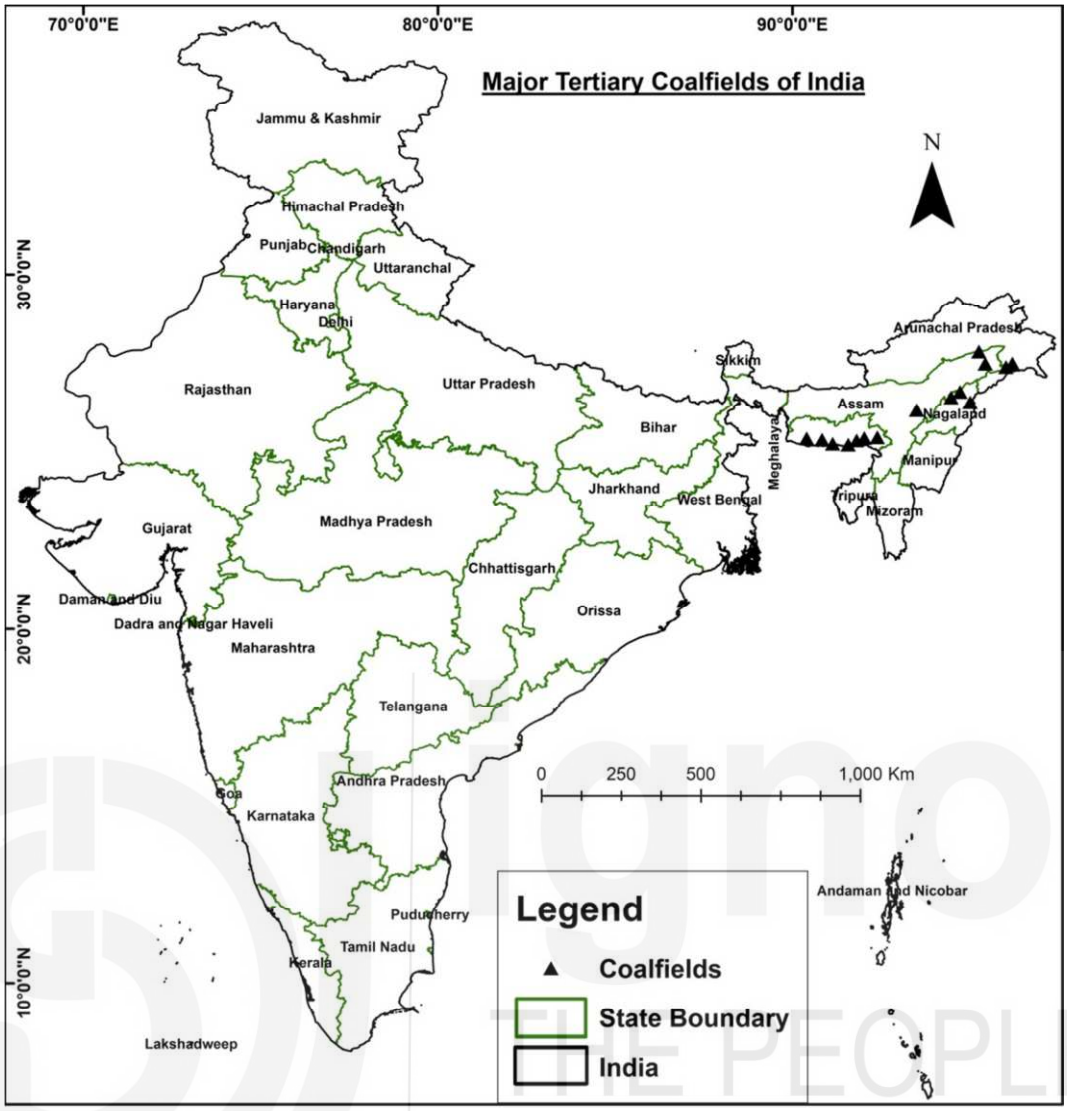

Fig. 15.6: Map showing major Tertiary Coalfields of India. (Prepared by Rohit Kumar)

Fig. 15.7: Tirap Open Cast Mine, Margherita, Assam.

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a) High volatile coal on heating in ambient air is converted to _____.

b) Chemical composition of coal is determined in terms of_____ and _____ analyses.

c) Three groups of macerals are _____, _____ and _____.

d) The process of conversion of peat into higher ranks is called _____.

e) The _____ is the measure of quality of coal, and is expressed as its heating value.

f) Coal deposits of India are classified into two groups as_____ and _____ coal.

15.3 PETROLEUM

We have read about constitution of coal, varieties, rank, grade and origin of coal in previous section. Now, we will discuss about origin, mode of occurrence of petroleum and it uses and formation of oil pool. Petroleum popularly known as liquid gold, also called **rock oil.** It is a natural fuel or a mineral fuel. The word petroleum is derived from the Latin word *petra* means rock or stone, and *oleum* means oil. Petroleum occurs widely in the Earth as gas, liquid, semisolid, or solid, or in more than one of these states at a single place. It is a complex mixture of hydrocarbons and some other compounds that occur in a liquid form, entrapped within the rocks of the surface of the earth. It is the most important source of energy today and is used mostly for producing fuel and gasoline. Due to its high energy density, easy transportability and relative abundance, it has become the world's most important source of energy since the mid 1950s E.L. Drake drilled the first well for oil in Pennsylvania in 1859.

15.3.1 Chemical Composition

Chemically petroleum is a complex mixture of hydrocarbon (i.e hydrogen and carbon) compounds, with minor amount of nitrogen, oxygen, and sulphur as impurities. Liquid petroleum is called crude oil. It consists chiefly of the liquid hydrocarbons, with variable amount of dissolved gases, bitumen, and impurities. Bitumen are black viscous mixture of hydrocarbons, obtained naturally or as a residue from petroleum distillation. In some cases, traces of metallic elements like vanadium and nickel are also found in crude oil. Crude oil (Fig. 15.8) is brownish black in colour with a greenish tinge. It is immiscible with water and floats on it. But it is soluble in naphtha, carbon disulphide, ether, and benzene. It has a characteristic odour typically petrol-like smell or rotten egg odour. Petroleum gas is commonly called natural gas. It is often associated with the petroleum deposits. Petroleum gas consists of lighter paraffin hydrocarbons, of which the most abundant is the methane gas (CH_4). The solid and semi-solid forms of petroleum consist of heavy hydrocarbons and bitumen. Depending upon their individual characteristics, they are called asphalt, tar, pitch, albertite, gilsonite, or grahamite.

Fig. 15.8: Crude oil sample.

15.3.2 Origin of Petroleum

Petroleum and natural gas originate from organic material buried in marine muds. It involves the reaction of carbides within the Earth to form acetylene and subsequently produce natural hydrocarbons. Organic material buried in marine sediments underwent chemical changes due to increased pressure and temperature generated by overlying sediments to produce natural hydrocarbon. Such hydrocarbons subsequently moved into porous sedimentary rocks known as **reservoir rocks** such as sandstone, coarse sands, porous limestones, conglomerates, dolomites and other argillaceous rocks. They accumulate to form oil pool. The source rock for petroleum are usually the fine-grained muddy sediments or marl (a mixture of mud and carbonate clay). They are rich in organic matter derived from alteration of algae, bacteria or plant debris for their oxygen free decomposition or conversion into petroleum. Slow oxygen free decomposition of remains of plants and animals of microscopic nature is considered to be the original source of petroleum. Conversion of organic matter into petroleum hydrocarbons is mainly due to bacteria which flourish in the upper mud of the sea floor.

15.3.3 Mode of Occurrence

Petroleum deposits are classified based on mode of occurrences. On this basis, petroleum occurrences may be broadly divided into two main divisions:

(a) **Surface**

(b) **Subsurface**

Petroleum occurs at the surface of the ground in a variety of ways. Some surface occurrences may be thought of as currently active, such as those that form seepages (Fig. 15.9), exudations of bitumen, those associated with the springs, mud volcanoes and mud flows. Petroleum, gas, or liquid asphalt that exudes in the form of springs and seepages may reach the surface along fractures, fault planes, joints, unconformities, or through any of the connected porous openings of the rocks. Some of the common types of seepage are shown diagrammatically in the (Fig. 15.10).

Fig. 15.9: Photograph of oil seepage, Namdang river, Assam.

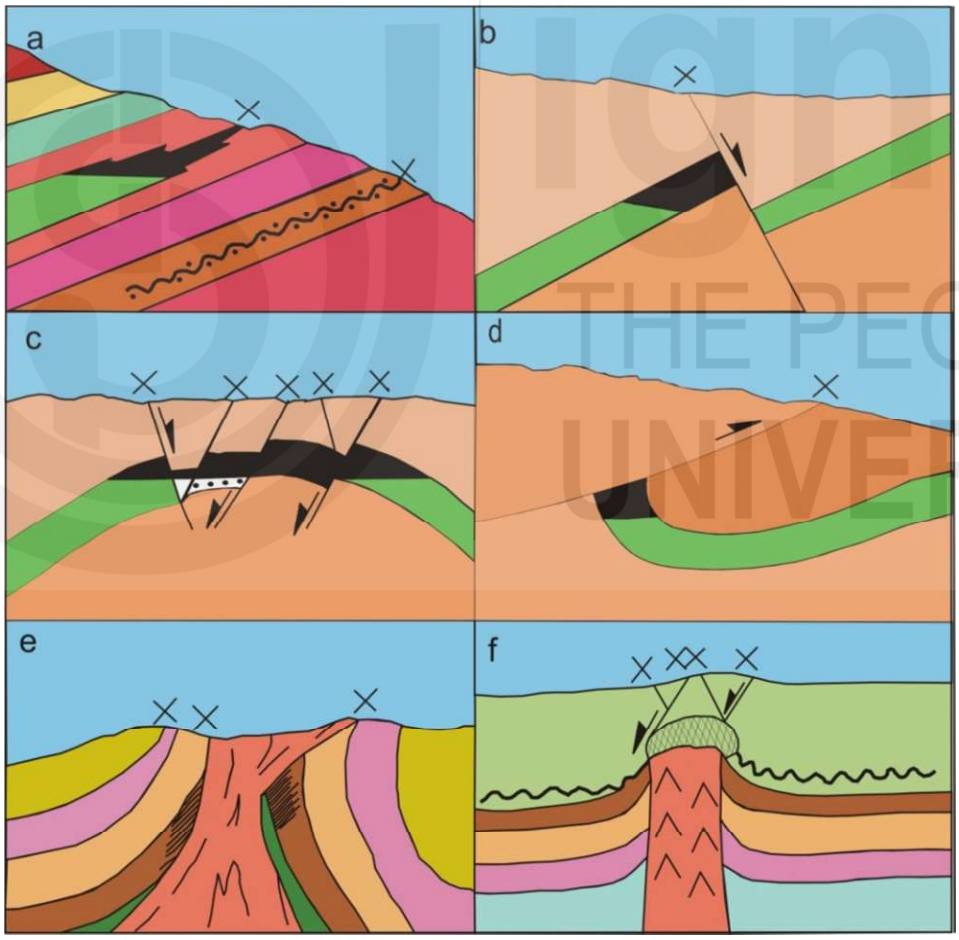

Fig. 15.10: Sections showing the position of typical seepages inrelation to the underlying structure. Seepages are marked X, and oil and gas pools are cross-hatched:a) Seepages at the outcrop of the pool and at the outcrop of an unconformity;b) Seepage is along the outcrop of a normal fault;c) Seepages overlie a faulted anticline;d) Seepage is along the outcrop of a thrust fault; e) Seepages are associated with diapir folding (an anticline in which a mobile core, has ruptured the more brittle overlying rock; andf) Seepages overlie a salt plug and are associated with the faults that occur above this intrusion.

Subsurface or underground petroleum occurrences are broadly divided according to their size as minor shows of oil and gas; and oil and gas pools, fields and provinces. Some natural gas and crude oil are found in most wells drilled in sedimentary rocks. Nearly every exploratory well finds some indication of gas or oil, even if it may be so minor that the well is abandoned as a dry hole. These are called minor showings. Exploratory well is a test hole drilled on land or in sea to ascertain the scope of recoverable gas and/or oil in a probable, but, yet-unproved location. It is the drilling for oil or gas in new areas, seeking to find new wells. Commercial petroleum deposits are classified as pools, fields and provinces. The simplest unit of commercial occurrence is the pool. When several pools are related to a single geologic feature, the group of pools is termed as field. A petroleum province is a region in which a number of oil and gas pools and fields occur in a similar or related geologic environment

15.3.4 Formation of Oil Pool

Oil pools are accumulation of oil in large quantities in porous sedimentary rocks. For the formation of oil pool certain conditions are necessary. They are as follows:

- Migration and accumulation,
- Suitable reservoir rocks,
- Suitable traps and
- Retention.

As petroleum is lighter (less dense), it tends to occupy larger space than available. This results in the development of great pressure (fluid potential) gradient which forces petroleum to migrate out of the site of its origin. The forces help in migration of petroleum due to compaction of muds, gravity, capillary action, currents and buoyancy.

The most important factors that control the accumulation of oil and formation of oil reservoirs are lithology and structural features of the rocks. Accumulation takes place in porous and permeable rocks. The most suitable reservoir rocks are loose, unconsolidated sands and porous sandstones. Igneous, metamorphic and impervious sedimentary rocks do not form good reservoir rocks.

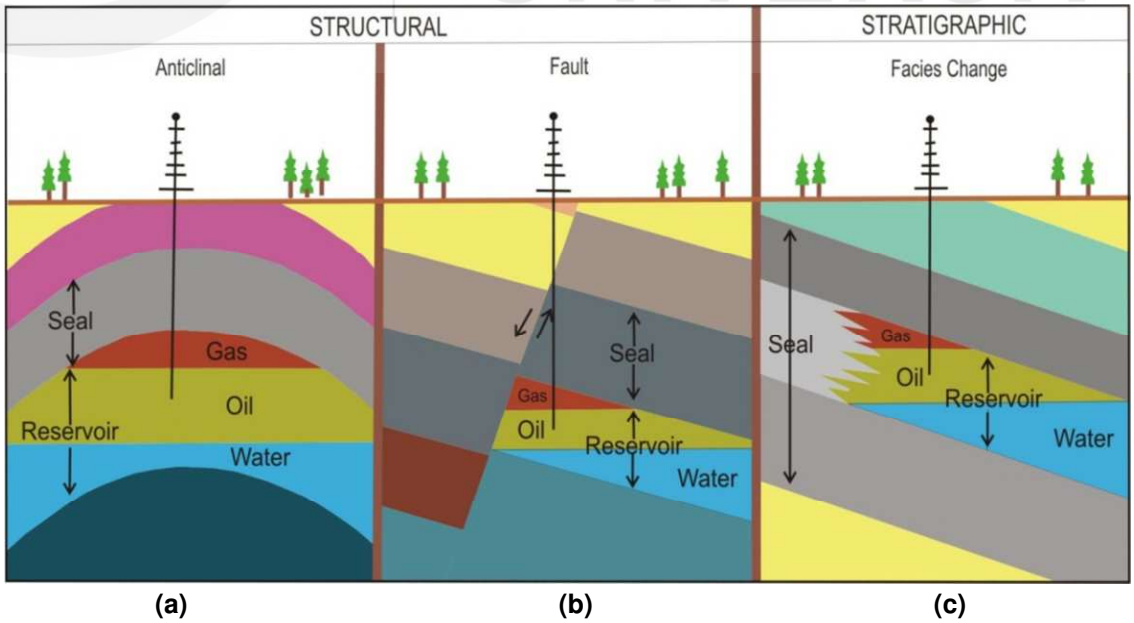

Fig.15.11: Schematic illustration of different types of Traps of petroleum accumulation: a) and b) Structural; and c) Stratigraphic.

There are two types of traps (Fig.15.11a and b) which hold the oil accumulation from getting away from the place of accumulation. They are:

i) structural traps

ii) stratigraphic traps and

The combination of these two types of traps may also occur.

Structural traps are the result of changes in the structure of the reservoir rock and are formed chiefly as a result of folding and faulting. Some of the most important structural traps are anticline, dome, monocline, faults, fissures and salt domes. Stratigraphic traps are the result of a lateral variation in the lithology of the reservoir rock, or a break in its continuity. Some of the important stratigraphic traps are, unconformities, buried coral reefs, over laps etc.

15.3.5 Indian Occurrences

Like many other countries, India is oil deficient country and imports huge amount of oil to meet its demand. In India basically 26 sedimentary basins have been found which are petrolifeous in nature. Some of the important oil reserves are found in Assam, Gujarat, Maharashtra and Rajasthan. In Assam, oil is extracted from oil fields of Digboi, Naharkatiya, Moran, Rudrasagar and Lakwa. Some of the well-known oil fields of Western India are Ankleshwar oilfield in Gujarat, Mumbai High (Arabian Sea offshore) in Maharashtra, the Cambay oilfield, the Kalol oilfield. There are some good potential oilfields that are also found in Arunachal Pradesh, Tripura, Nagaland, Andhra Pradesh and West Bengal (Fig. 15.12). Some of the important oilfields are:

- **Digboi Oilfield:** The oilfield is situated in a part of the Naga Hills in the north-eastern part of India. The oil field occupies 13sq km area of Tinsukia District and occurs in an anticlinal trap.
- **Cambay Oilfield:** It is situated in Gujarat and in the Cambay-Kalol area north of the Gulf of Cambay and lies about 8km north-west of Cambay city. The oil deposits are found in the rocks of Oligocene age. The occurrence of oil is recorded in the off-shore region in the Arabian Sea.
- **Ankleshwar Oilfield:** The oilfield is situated about 81km SSW of Baroda, South of the Narmada river. The oil producing sands are of the Eocene age. The oilfield is situated on an elongated doubly plunging anticline and dome.

Coastal Oilfield: The oil bearing marine sediments of the Cretaceous and Tertiary age is the source of oil found along the East Coast of the Peninsular India which includes Andhra Pradesh, Tamil Nadu and Orissa Coastal areas.

15.3.6 Uses

Petroleum is the key fuel of modern times and is of immense value in the development of a country. Crude oil is refined and distilled in petroleum refineries to separate a number of petroleum compounds such as petrol, diesel, kerosene, propane, butane etc. Petroleum is used as a primary source of heat and energy, as a basic raw material in the petro-chemical industries, automobiles and engine fuels, used to generate electricity used in the manufacture of fertilisers, insecticides, explosives, perfumes, chemicals, toilet products, synthetic rubber, resins, textiles, medicines etc. Crude oil is condensed and fractionated to fluids, such as gasoline, kerosene, benzene etc.

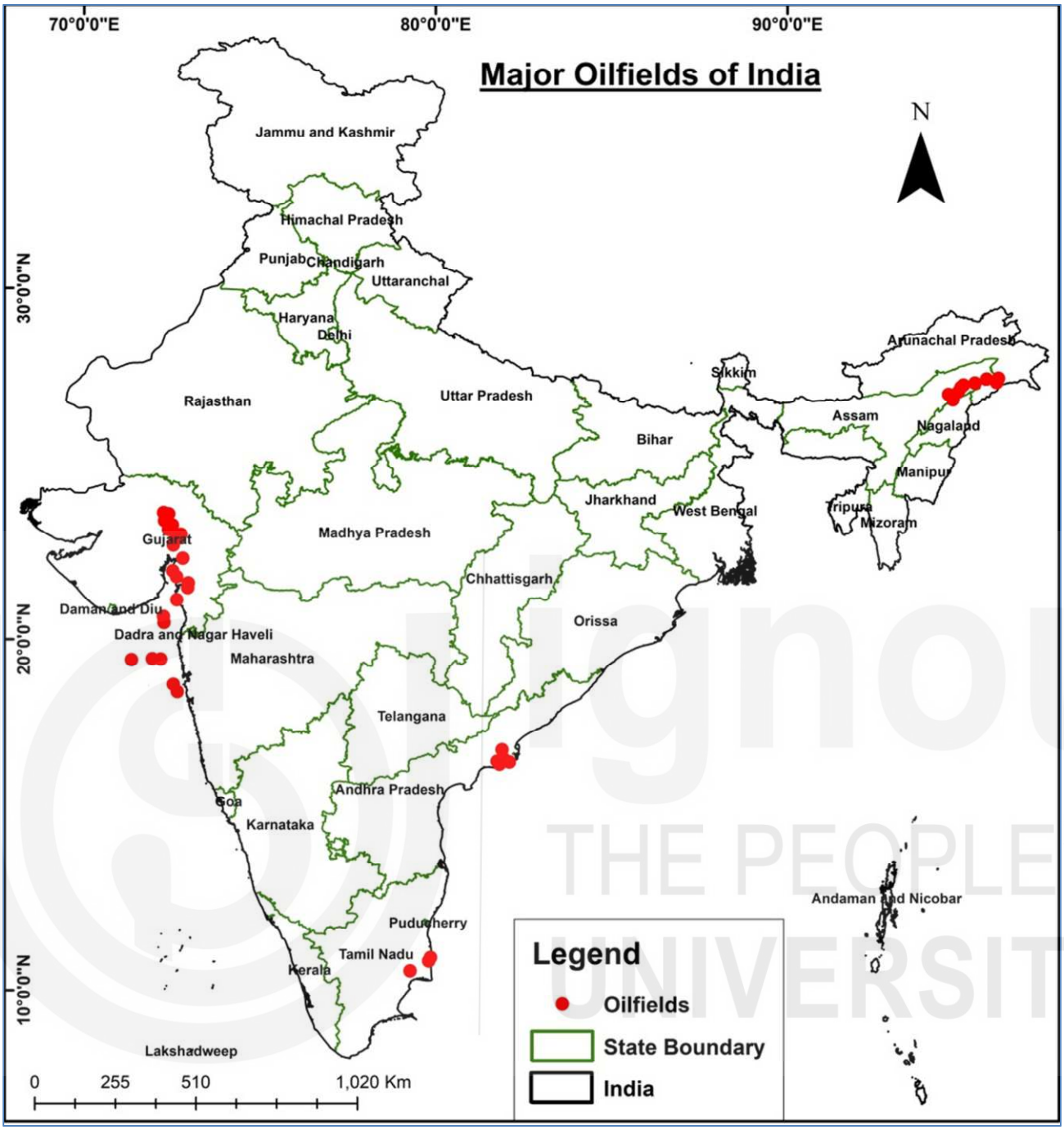

Fig.15.12: Distribution of major oilfields in India. (Prepared by Rohit Kumar)

SAQ 2

a) What is crude oil?

b) Name two types of petroleum traps.

c) Name productive off shore oil basins of India.

d) List some important structural traps.

15.4 ACTIVITY

- Plot the distribution of important coalfields and oilfields of India in map of India.

15.5 SUMMARY

Let us sum up what we have studied in this unit.

- Coal is one of the principal fossil fuels and is a primary source of energy and power. Chemically, it is composed of various proportions of carbon, oxygen, hydrogen with small amounts of nitrogen, sulphur and carbon being the major components.
- The coal bands are classified into four types, namely, vitrain, clarain, durain, and fusain.
- The constituents of coal may be distinguished into number of units under the microscope, which are called macerals and are classified in three groups: vitrinite, exinite (or loptinite) and inertinite.
- Theories of origin of coal are the in-situ theory, i.e. the coal forming materials was deposited and transformed where it grew, and the other is the drift theory i.e. the plant material has been transported and deposited in suitable places to form coal.
- Based on the rank of the coal is divided into four major classes: Peat, Lignite, Bituminous and Anthracite in order of progressive maturity.
- The grade is the measure of quality of coal, and is expressed as its heating value. The more the amount of carbon in coal, better is the grade.
- Coal deposits of India are classified into two groups: Gondwana Coals and Tertiary Coals.
- Coal has been used as an energy resource, primarily burned for the production of electricity and heat. They are used in the manufacture of metallurgical coke as fuel in stream raising, heating and producing gas besides in making of coke.
- Petroleum occurs widely in the Earth as gas, liquid, semisolid, or solid, or in more than one of these states at a single place. It is a complex mixture of hydrocarbons and some other compounds that occur in a liquid form entrapped within the rocks of the surface of the Earth.
- Petroleum and natural gas originates from organic materials buried in marine muds which involve the reaction of carbides within the Earth to form acetylene and subsequently produce natural hydrocarbons.
- Petroleum occurrences may be broadly divided into two main divisions i.e. surface and subsurface occurrences. Migration and accumulation, suitable reservoir rocks, suitable traps and retention are the conditions necessary for the formation of oil pool.
- The two types of traps which hold the oil accumulation from getting away from the place of accumulation are structural traps and stratigraphic traps.
- Some of the important oil reserves are found in Assam, Gujarat, Maharashtra and Rajasthan.
- Petroleum is used as a primary source of heat and energy. As a basic raw material in the petro-chemical industries, automobiles and engine fuels, used to generate electricity, used in the manufacture of fertilisers, insecticides, explosives, perfumes, chemicals, toilet products, synthetic rubber, resins, textiles, medicines etc.

15.6 TERMINAL QUESTIONS

1. Discuss the macroscopic unit of coal?
2. Give a brief account of the geographical distribution of coal deposits of India.
3. Discuss briefly the origin of coal and petroleum.
4. Describe mode of occurrence of petroleum deposits in India.
5. Draw neat, labelled sketches to illustrate important types of oil traps.

Audio/video material based questions

- List the sedimentary ore deposits.
- What are hydrocarbon deposits?
- What is bituminous sedimentary process?

15.7 REFERENCES

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15.8 FURTHER/SUGGESTED READINGS

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15.9 ANSWERS

Self Assessment Questions

1 a) Coke.

b) Proximate and ultimate or elemental analyses.

c) Vitrinite, Exinite and Inertinite.

d) Coalification.

e) Grade.

f) Gondwana and Tertiary.

2 a) Liquid petroleum is called crude oil and consists chiefly of the liquid hydrocarbons, with variable amounts of dissolved gases, bitumens, and impurities. Crude oil is brownish black in colour with a greenish tinge, immiscible with water and floats on it, but is soluble in napththa, carbon disulphide, ether, and benzene. It has a characteristic odour typically petrol-like smell.

b) Structural and stratigraphic traps.

c) Bombay High.

d) Some of the most important structural traps are anticline, dome, monocline, faults, fissures and salt domes.

Terminal Questions

1. The bands of the coal are vitrain, clarain, durain, and fusain. Vitrain is the brightest portion or band of a coal. Usually, it occurs as a thin band. Clarain is less bright than the vitrain. It occurs in bands of variable thickness. It is bright in colour and shows silky lustre. It does not show conchoidal fractures. Durain is typically dull coal and occurs as thick bands. It is hard, greyish black in colour and breaks with irregular surface. Fusain resembles charcoal. It is black in colour, powdery in nature. It occurs as patches and wedges and shows fibrous structure.
2. Please refer to subsection 15.2.1.
3. Please refer to subsections 15.2.5.
4. Please refer to subsection 15.5.
5. Draw the structural and stratigraphic traps as shown in Fig. 15.12.

GLOSSARY

Acid rocks : These are rocks consisting of silica rich minerals like quartz, alkali feldspar and muscovite in large amount. They comprise more than 65% silica.

Alluvial ore-deposit : This is a type of ore deposit in which deposition of mineral grain takes place by flowing water.

Alteration : This involves the process of physical or chemical change in the rocks or minerals after their formation.

Amorphous : This term is used for those rocks, minerals and materials which have no form and definite crystal structure.

Anhydrite : This mineral is composed of anhydrous $CaSO_4$ and crystallises in orthorhombic system. It's colour is white sometimes with greyish, bluish and reddish tinge.

Arenaceous : This is the term used for rocks which are sandy or have sandy texture.

Argillaceous : This is the term used for clayey rocks which comprise clay.

Assimilation : This is a complex process in which invaded country rocks by invading magma are partially or completely melted at the contact zone and incorporated at deeper levels.

Aureole : Geologically this term is used for the zone enclosing the intrusive igneous rocks in which country rock undergoes contact metamorphism. This is known as contact zone.

Auriferous : This word is used for gold rich deposits and ores.

Autometasomatism : In a newly crystallised magma this is the alteration done by late water rich liquid fraction released by it.

Autometamorphism : Metamorphism of igneous rocks by its evaporation of its own liquid fractions such as formation of spilite from basalt.

Banded structure : This is the term used for prominent layering or banding in veins or nodules. These types of structures are formed due to successive deposition or replacement of pre-existing rocks such as granite gneiss.

Basic rock : This is the igneous rock in which the minerals with less silica and sufficient alkali, like amphibole, pyroxene, biotite and olivine are comparably abundantly present.

Blanket deposit : It is a flattened ore deposit whose length and width is more than its thickness. Traditionally this term is used by miners and has no real scientific meaning.

Building stone : This term encompasses those rocks which are commonly used for construction of buildings, decoration, roofing and flooring.

Calcareous : This term is used for those rocks which are composed of calcium carbonate.

Calcification : Repalcement of hard parts of an animal or a plant by calcium carbonate.

China clay : The clay composed of feldspar which is used for making glazed pottery and porcelain.

Clastic rock : Broken rock material derived from pre-existing rock, example-sandstone, conglomerate etc.

Coalification : The process by which vegetable material is transformed into high quality coal and anthracite is its end product.

Coal measures : Beds with layers of coal especially of Carboniferous age.

Coal seam : Bed or layer of coal.

Coke : Bituminous coal in which volatile components have been removed by heating. This is commonly artificial product however natural coke also occur.

Comb structure : Comb like structure in of crystal aggregates in mineral veins.

Conchoidal : This term is used to describe nature of the fracture.

Conglomerate : This rock is composed of relatively eroded and rounded rock pieces or cobbles formed due to action of water.

Contact deposit : This term is mainly used for mineral deposit occurring between the two dissimilar rocks. This type of ore body occur at the contact of sedimentary and igneous rocks.

Crude oil : Natural petroleum; Crude petroleum extracted from inside the Earth.

Crustification : Formation of mineral or ore deposit in the form of layers or crust.

Deposit : This is the material accumulated by some agents.This term was initially used for materials (suspended) brought by flowing water. But now this also includes accumulated mineral materials whether they are deposited by chemical agent or precipitated by other agents such as ore in veins.

Detrital : Derived or related to detritus.

Dissemination In the beginning of crystallising magma. Ore minerals are present in scattered form.

Dolomite : It is a mineral composed of calcium magnesium carbonate varying from white to pink colour. Its crystals are rhomboherdral in shape.

Evaporite : This is type of sediment which is deposited due to complete evaporation hydrous solutions from solvents.

Extrusion : Emission of magmatic material on the Earth's crust.

Fayalite : It is a mineral of olivine group with composition Fe_2SiO_4

Felsic : It is the term used for rocks containing one or more minerals with sufficient silica like feldspar, feldspathoid and silica.

Ferriferous : Consisting of iron or with iron.

Filling deposit : Deposits which fill the cavities.

Fissure : It is a crack or fracture in a rock by which its wall is clearly separated. Fissure can be filled with mineral material.

Fissure vein : Fissure vein is the flattened ore body which is surrounded by one or more fissure. Its two dimensions are bigger than the third dimension. Fissure veins are important than all the cavity fillings and are found in many ranges. In which more than one metal or mineral can be found. It is of six types-simple, mixed, serial, blanket, or crustified.

Flint : It is a lusterless, and coloured fine grained microcrystalline silica displaying conchoidal fracture.

Flux : Material to reduce the melting point of a mixture.

Geothermal : Concerned with heat of the interior of the Earth

Gondite : Metamorphic rock comprising spessartine variety of garnet.

Halite : Common or rock salt found as amorphous, crystalline or granular. On crystallizing it is found as cube.

Heavy minerals : Minerals with relatively more density than bromoform (Sp. gr. 2-9).

Intermediate rock : It is the term used for those igneous rocks between basic and felsic rock groups. They consist of silica between 52 and 65%.

Intrusive rock : These are the igneous rocks which solidified below the Earth's crust. Intrusive rocks are found as dyke, sill, stock and batholith.

Jasper : It is commonly red or brown coloured microcrystalline quartz.

Kaolin : It is white or nearly white coloured clayey rock formed due to decomposition of feldspar containg rocks. It is used to make porcelain rich paste.

Kimberlite : An alkalic peridotite containing abundant phenocrysts of olivine (commonly altered to serpentine or carbonate) and phlogopite (commonly chloritised), in a fine-grained groundmass of calcite, second-generation olivine and phlogopite with accessory ilmenite, serpentine, chlorite, magnetite and perovskite. The name is derived from Kimberley, South Africa where rock contains diamond.

Khondalite : Khondalite is quartz–manganese-rich garnet–rhodonite schist. It may also contain sillimanite and graphite. It is found in the Eastern Ghats between Vijayawada and Cuttack in India.

Lode : Commonly this word is used for late formed ore deposits whose thickness is less than depth and length. It is synonym to vein.

Mafic : Term used for rock rich in iron magnesium minerals.

Mineral deposit : Metallic or non-metallic mineral materials or local accumulation of any mineral having economic values or futuristic economic value.

Oil shale : The shale containing hydrocarbon in the ration that mineral oil can be derived from mild distillation.

Oolite : Rock commonly consisting of small spheroidal or ellipsoidal grains less than 2mm. They have been derived from inorganic precipitation.

Lamellar layer : The direction in anisotropic crystals in which double refraction does not take place.

Peat : It is a brown or black coloured residue formed due to partial disintegration or decomposition of mosses or other plants in Kutch or similar places with other names.

Porosity : It is the ratio of the aggregate volume of interstitial spaces present in rock or soil total volume of rock or soil. It is expressed in percentage.

Refractory : Especially resistant to melting on heating and commonly resistant to chemical reaction.

Ribbon structure : Structure commonly found in quartz veins which is separated by thin back bands of quartz consisting of narrow layers of altered wall rock.

Wall rock : The rock forming the walls of a vein, lode or igneous intrusion.