Mining Geology & Development of Mineral Deposits

Petrology, Stratigraphy & Mineralogy

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Petrology

Petrology literally means study of rocks, (petro = rock; logos = study.) Lithology (litho = rock) is a synonymous term but used only in certain contexts. The subject matter of petrology comprises the origin, association, occurrence, mineral composition, chemical composition, texture, structures, physical properties, etc., of rocks.

DEFINITION OF A ROCK

In spite of the vast variety and complexity of rocks, a rock may be simply defined as "*an aggregate of minerals*". Since the crust of the earth is composed of rocks, a rock may also be defined as "a unit of the earth's crust". There are many mineral species (approximately 1600) occurring in nature. Since the occurrence of different minerals or different proportions of the same mineral combinations can give rise to different rock types, there is scope to imagine innumerable varieties of rocks.

CLASSIFICATION OF ROCKS

The rocks are classified in various ways based on different principles such as physical classification (as stratified and unstratified), chemical classification (calcareous, siliceous, etc.), geological classification (igneous, sedimentary, metamorphic), etc. Among the different classifications, geological classification is the most proper because grouping of rocks is more logical, less ambiguous, orderly and comprehensive. The geological classification of rocks is based on their mode of origin.

IGNEOUS ROCKS

A rock that has solidified from molten lava or magma is called an igneous rock. However, rocks formed by the consolidation of molten magma are said to be primary rocks. These rocks are formed when volcanic lava solidifies, Generally, igneous rocks are massive in form. It is supposed that these rocks are the oldest ones formed on the earth's crust.

Examples: Granite, gabbro, dunite are formed by the consolidation of magma. Basalt and trachyte are formed due to the solidification of lava.

As mentioned later, igneous rocks are the first formed rocks which had made up the primordial (i.e., original) earth's crust. For this reason these are called primary rocks, even though igneous rocks have been formed subsequently also. Igneous rocks are the most abundant rocks in the earth's crust. In fact, their abundance is so much that their average composition closely tallies with the chemical composition of the earth's crust itself. The igneous rocks are formed at a very high temperature directly as a result of solidification of magma or lava. Different types of igneous rocks are formed as products of magmatic differentiation or assimilation.

Magma and Lava

Both these refer to melts of rocks which are compositionally silicate rich. The term magma is applied when the melt is underground. The same, when it reaches the earth's surface and flows over it, is called lava. Thus, based on the mode of occurrence, the melt of rocks is described either as magma or lava. Apart from this, a little compositional difference also occurs between the two. Magma is always associated with huge quantities of various volatiles. But when it flows on the surface, these volatiles escape into the atmosphere. Therefore the lava is devoid of such volatiles.

Typical Characters

The igneous rocks are often characterized by the presence of *crystalline minerals* and an interlocking texture. These show indications of having been formed from a high temperature rock melt. They are usually massive, unstratified, unfossiliferous, have apophyses and often occur as **intrusives** cutting across other rocks (country rocks) which they might have heated, baked and altered. The volcanic igneous rocks are always extremely fine grained and they may be massive or vesicular or amygdaloidal.

Formation, Occurrence and Crystallization of Magma

Magma is the parent material of igneous rocks. Anywhere on the earth, the temperature increases proportionately with the depth. The rate of increase of temperature of this kind, however, varies place-wise and depth-wise. So, it is natural to expect that at very great depths, the prevailing temperatures must be capable of melting the rocks, thereby producing magma. This is one of the reasons for the formation of magma.

The heat generated by processes such as radioactive mineral disintegration may also help this process. But below the earth, magma does not occur everywhere. This is so because, just as temperature increases with depth, pressure also increases with depth due to increase of overburden. The effects of these two mutually associated phenomena are different. The rise in temperature tends to increase the volume of the material, whereas the rise in pressure tends to decrease the volume of the material. Hence, depending upon local conditions where the pressure effect is less than the effect of temperature, magma is formed. But in those places where the pressure effect is more than the temperature effect, magma cannot form because the formation of hot magma (melt) from rocks (solid) has to be accompanied by necessary volume increase. If pressure is dominant, it will not permit increase in volume. That means magma is not allowed to form, even though the prevailing temperatures may be capable of producing magma. In view of these complications, and other factors, magma occurs below the earth only as isolated packets or chambers and not as a continuous body. It is locally generated due to loss of pressure when deep seated fractures reach high temperature areas at a depth.

After its formation, the magma moves upwards and gets surrounded by relatively colder rocks which results in gradual loss of heat from the body of the magma. Because of this, solidification or crystallization of magma follows. The rate of cooling of magma depends on the size of the magma chamber and other conditions. Accordingly, the cooling of thick sills or huge batholithic bodies may take decades. Small bodies of magma will solidify quickly and directly producing homogeneous igneous rocks. But in case of huge magmatic bodies, the process of solidification is often accompanied by differentiation or assimilation or both. Differentiation is a process whereby a magma, originally homogeneous, splits into parts of contrasted composition and then solidifies giving rise to rocks of different compositions. The differentiation phenomenon occurs in nature due to various reasons like gravity, liquid immiscibility effect, filtration effect, crystallization effect, volatiles effect, etc. In some cases, if magma contains considerable superheat, it further melts the walls, roof, etc., of the magmatic chambers and digests or assimilates them. Or, sometimes, two liquid magmas of different compositions may mix together forming new homogeneous magma. These phenomena are called assimilation. In one way assimilation appears as a reverse process of differentiation because this involves mixing of bodies (rocks/magma) of different compositions resulting in the formation of a homogeneous magma of a different composition. Sometimes, the incorporated rock bodies are not completely digested by the magma. In such cases, they appear as xenoliths in the igneous rock formed. These masses of rocks are called **hybrid rocks**.

Sequence of Events in the Crystallization of Magma

Magma is composed of non-volatile and volatile constituents. With falling of temperature, when magma begins to crystallize, the non-volatile constituents come out to form the rock-forming minerals, i.e., mostly the silicates, which are characteristic of the usual igneous rocks - this stage is called orthomagmatic stage. The separation of the non-volatile constituents leads to the concentration of the volatile components, with the result that the residual portion of the magma is rich in fluxes, i.e., various gases and vapours. The liquid part of the residual magma forms the pegmatitic stage and the gaseous part forms the pneumatolytic stage. The final consolidation of magma takes place from the last hot water-rich mineralized solutions. This is the hydrothermal stage.

Extrusives

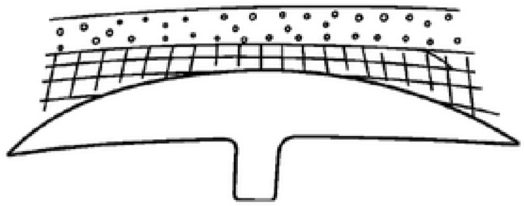
Extrusive rocks are of a wide variety, depending on the nature and amount of erupted material and its association with the country rock.

A volcano is considered as a conduit between the earth's surface and the body of magma, the crust beneath it. During volcanic eruption, lava is extruded from the volcanic vent and gases contained in the lava are ejected through it. Depending on the type of eruption, lava flows are divided into two groups: (a) fissure eruption (b) central eruption.

Intrusives (Minor)

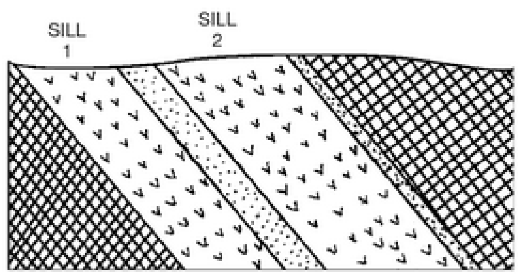
Sills

Sills are relatively thin tabular bodies of magma which essentially penetrate parallel to the bedding pianos of foliations of the country rocks. Sills are typically thin and shallow and are mainly located on unfolded country rocks. They are mostly basaltic in composition. A high degree of fluidity is essential to produce a sheet-like form. Sills are grouped into two types based on their ejection. Simple sills are those which are formed due to a single ejection.



Simple sill

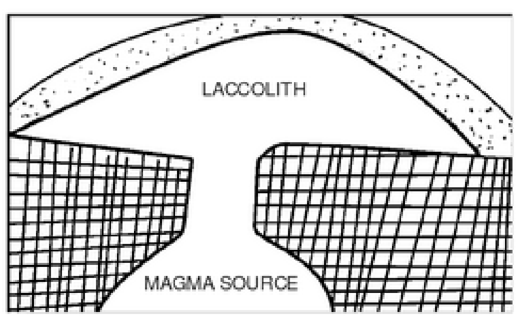
Multiple sills are formed as a result of more than one ejection.



Multiple sill

Laccoliths

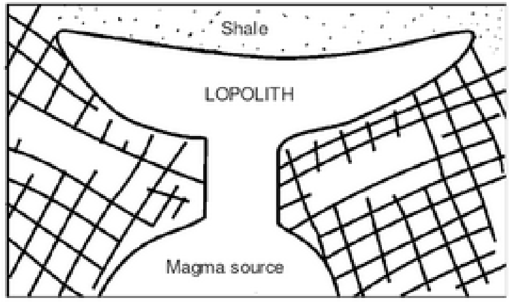
A laccolith is an intrusion with a flat floor and domed roof, the roof having been arched by the pressure from magma. High viscosity magma does not spread over but tends to form a bun shape (see figure).



Laccolith

Lopoliths

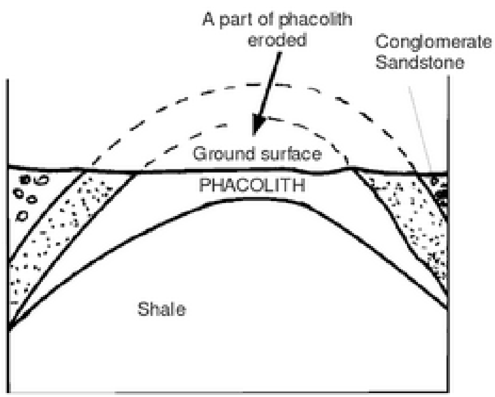
According to Grout's description, a lopolith consists of a large, lenticular, centrally sunken, concordant basin or tunnel -shaped intrusive mass (see figure).



Lopolith

Phacoliths

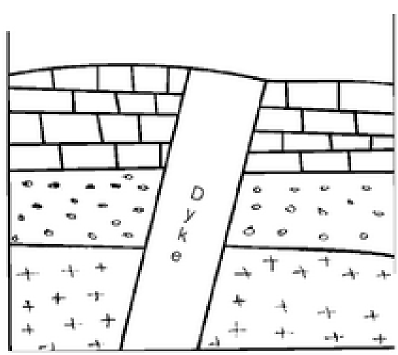
Phacoliths are intrusive concordant bodies mainly associated with folded rocks (see figure).



When they occur in a syncline, they are doubly convex downwards; when occurring within an anticline they are doubly convex upwards.

Dykes

Dykes are the intrusion of magma into vertical fissures which tut across the bedding of the country rock see figure).



Many dykes are more resistant than the surrounding rocks. Dykes vary in size from a few metres to a few hundred metres and extend from a few metres to a few hundred kilometres. However, the majority of dykes are only several metres in thickness.

DESCRIPTION OF SOME IMPORTANT IGNEOUS ROCKS

Granite

Granite is a plutonic igneous rock because it is formed due to solidification of magma at great depths. It is a holocrystalline and leucocratic rock because it is completely crystalline and a light coloured rock. It is an acidic and oversaturated rock because it is very rich in silica content (nearly 72%) and has free quartz.

Minerals Present in Granite

Granite is composed of only primary minerals. Among these, feldspars and quartz occur as essential minerals and the common accessory minerals are mafic minerals such as hornblende, biotite, hypersthene, augite, muscovite, magnetite, pyrite and epidote. Of these, *hornblende* and *biotite* are particularly common in granites. In case of essential minerals, feldspars account for roughly 60% of granite. Quartz is usually present to the extent of 25 to 30%. The accessory minerals are generally less than 15%.

Structure

Granite is a compact, dense, massive and hard rock. But mural joints (two sets vertical, one set horizontal - all mutually perpendicular) occur in some, dividing the rock into a number of rectangular blocks, thereby facilitating the *quarrying process*. Along with mural joints, granites may also have two sets of micro fractures (one set horizontal, the other set vertical) called rift and grain. Rock breaks more easily along the rift than the grain. Granites are unstratified.

Texture

Granites typically exhibit an interlocking, phonetic coarse grained texture (of course, some granites are medium and fine grained too). Granites are usually equigranular. But some show an inequigranular, porphyritic texture and are called granite porphyrys. In such rocks feldspar occurs as phenocrysts. In some, two generations of feldspars occur. In such a case, the former set occurs as phenocrysts, while the latter is found in ground mass. Some granites of eutectic origin exhibit graphic texture, which resembles cuneiform or Arabic writing. These types of rocks are called *graphic granites* and are composed exclusively of feldspars and quartz without any accessory minerals.

Appearance of Granite in Hand Specimen

Granite is generally medium to coarse grained and greyish or pinkish in colour. The cleavage-bearing feldspar appears with a bright lustre and is white or brownish-red coloured. Quartz looks colourless. Biotite is jet black and is found as small shining flakes. Hornblende is dark greenish black with a subvitreous lustre.

Mode of Occurrence and Relative Abundance

Granitic rocks occur in the form of very large igneous bodies such as batholiths, stocks and bosses. Often they occur as cores of mountain ranges and are thus related to mountain-building activity. The granitic rocks which are of deep seated origin are seen on the earth's surface because of long, continued erosion (for millions of years) of overlying rocks or tectonic activity such as faulting or both. The upper portion of the earth's crust, known popularly as "**sial**" is in general composed only of granitic rocks. Granitic rocks are very abundant. They are estimated to be twenty times greater in quantity than all other plutonic rocks put together.

Physical Properties of Granite

- Granite is massive, unstratified and dense (specific gravity 2.6-2.8; density = 2500 to 2650 kg/cm^3); therefore it is very strong and competent (compressive strength = 1000 to 2500 kg/sq. cm).
- Granite has an interlocking texture, which keeps minerals firmly held, and this cohesion contributes greatly to the strength of the rock.
- Granite is either equigranular (with a few dark minerals) or has a porphyritic texture. These factors enable granite, on polishing, to take or a mosaic appearance or a mottled appearance respectively.
- Since granite is massive and formed from melt it is neither porous (porosity is < 1 %) nor permeable (absorption 0.5 to 1.2%). So no saturation or percolation by water is possible. Therefore, the rock will not become weak in the presence of water and also it remains durable.
- Granite is very rich in silica; therefore it is very much resistant to decay, i.e., weathering.
- The constituent minerals of granite are very hard. This makes the rock tough and resistant to abrasion. (Hardness coefficient = 18.)
- Presence of mural joints facilitates easy quarrying.
- Presence of rift and grain permit easy dressing, i.e., easily workable.
- Being the most abundant plutonic rock, it is found in plenty and is easily available in many places.
- As its essential minerals are pale coloured, it often has pleasing colours of pink and grey in various shades.
- Granites offer reasonable//re and frost resistance, because minerals are not many and these rocks are free from fractures.

Gabbro

Gabbro is a plutonic rock. These rocks are useful in various civil engineering constructions. **Mineral composition**. Essential minerals are plagioclase (generally laboradorite) and monocline pyroxenes (augite). Accessory minerals such as hornblende, biotite, hypcrsthene and olivine occur in some varieties like nepheline apatite and magnetite.

Texture: (Grain size, coarse. Some varieties show a porphyritic texture.

Varieties: Hornblende gabbro, biotite gabbro, nepheline gabbro (essexite), norite (hypcrsthene gabbro) anorthosite, labrodite dunite, olivine and pyroxenes.

India's Resources: Tamil Nadu gabbros and anorthosites are exposed near Pottalur, Salem and Cauvery basin from Sittam Pundi to Suryaptti. Gabbros and anorthosites also occur in Kadavur, Tiruirapalli, Tamil N'adu. Gabbro anorthosites associated with vanadiferous magnetite occur in East Singhbhum, Jharkhand.

Dolerite

The term dolerite refers to a dark, heavy, fine grained igneous rock. This is the most commonly found hypabyssal rock. It is intermediate in composition and characteristically melanocratic. Mineralogically and chemically it is similar to gabbro and basalt. It is fine grained compared to gabbro but coarse grained compared to basalt.

Minerals Present in Dolerite

Dolerite is a rock, normally composed of labradorite type of plagioclase feldspar and augite type of pyroxene as essential minerals. Iron oxides, hypersthene and biotite occur as common accessory minerals. In general, accessory minerals occur in very small quantities. Since the rock is intermediate, its minerals are generally saturated. But. if the parent magma was slightly deficient or surplus in silica content, the resulting dolerites will have small quantities of olivine or free quartz, respectively. Thus most of the dolerites are composed of plagioclase and augite and accessory minerals include quartz (or olivine). biotite, iron oxides, etc.

Mode of Occurrence

Very often, dolerite occurs in nature as an intrusive rock, i.e., as dykes (and less commonly as sills) in granites. These dark coloured (black or dark greenish black) rocks are prominently noticed in the field by virtue of colour contrast with surrounding granites which are light coloured. Further, in weathered areas, dolerite outcrops stand out as linear ridges or trenches because, they usually weather either more or less compared to the surrounding rocks.

Structure and Texture

Dolerite is a very dense, massive and compact rock. It is neither porous nor permeable. It is relatively heavier than granite as it is richer in mafic minerals. The texture is generally equigranular, phaneric fine grained.

Physical Properties and Uses

Dolerite has all the merits and virtues possessed by granite (see under granite) except its colour. Of course, pure black colour has great demand. Since dolerites are more fine grained, they are stronger and more competent than granites. Black granites have recently become good foreign exchange earners. They are produced mainly in Tamil Nadu and to some extent in Andhra Pradesh. However, some disadvantages are: Dolerite dykes are not rare but far less abundant than granites. So they cannot be seriously considered as sources of large supplies. Further, as these dykes are generally vertical or steeply inclined, with limited width (or thickness) quarrying them is naturally difficult. The greater toughness and lack of weak planes does not make them easily workable. Except pure black coloured and very fine grained types, the normally found dark greenish coloured dolerites with medium grain texture and dolerite porphyries are not used very much. For these reasons dolerites are not common as building stones. They are suitable as railway ballast, concrete or bitumen aggregate, etc. As road metal, though they do not have good cementing value like limestones, they can be used if locally available. At foundation sites of dam-like structures, occurrence of dolerite dykes is considered undesirable as they become a cause for heterogeneity and weak planes (i.e., along contact planes of intrusive with country rock). But the same feature sometimes serves as a structural trap for oil and gas deposits. Springs and seepages also may occur due to dolerite dykes.

Basalt

Basalt is a simple mixture of labradorite, augite (essential) and iron oxides. It is similar to dolerite in mineral content.

Structure and Texture

Vesicular and amygdaloidal structures are the most common in basalts.

Basalt refers to a massive, very fine grained melanocratic rock without vesicles or amygdales or quartz or olivine.

Basalt is typically melanocratic with uniform black or greenish grey or black with brownish or purplish tinge.

Basalts are the most abundant among volcanic rocks. Their quantity is five times greater than all other volcanic rocks put together. The basalts, as Deccan traps, are extensive in peninsular India and occupy an area of more than two lakh square miles. They are spread over Maharashtra, parts of Gujarat, Madhya Pradesh, Karnataka and Andhra Pradesh.

Massive basalts are highly durable and the strongest (having the highest load-bearing capacity or crushing strength). This is because not only are they compact, hard and tough but also more fine grained than dolerite. For this reason basalts are used fairly extensively as building stones in the areas in which they occur.

As road metal, the basalts (Deccan traps) are excellent for macadam and bitumen roads. They are hard, tough, wear-resisting and have good binding properties. They are also excellent for use as aggregates in cement concrete.

A number of tunnels have been made across these basaltic (Deccan trap) rocks for railway lines near Bombay. They need no lining, except sealing the joints or other weak planes to prevent seepage.

SEDIMENTARY ROCKS

Sedimentary rocks are formed by the consolidation of loose sediments or chemical precipitation from the solution at or near the earth's surface.

Sedimentary rocks are also called *layered rocks* because weathered sediments are transported and deposited on the oceanic floor in the form of layers. During the geological process, these layers are made compact, consolidated and uplifted to form layered rocks. These nicks show sedimentary features, such as ripple marks, stratification, cross-bedding, fossils (in some rocks), etc.

Examples: Sandstones, limestones, shales.

The branch of petrology which deals with the Study of sedimentary rocks and their equivalents is termed **sedimentary petrology**. Common sediments, such as sandstone, shale and limestone, form 95 per cent or more of all sediments.

Mineral fuels of sedimentary origin such as natural gas, petroleum and coal are available in sedimentary rocks.

Origin of Sedimentary Rocks

Sedimentary deposits are solid materials lodged at or near the surface of the earth under low temperature and pressure. The formation of sedimentary deposit depends on (a) provenance (b) transportation (c) deposition.

- **Provenance:** The formation of sedimentary deposits depends on the source rocks, their degrees of erosion and transporting agencies. For instance, weathered and fractured granitic or silica-rich and metamorphic rocks liberate weathered fragments. Formation of a particular sedimentary rock depends on the mineral composition of the original weathered rock. Sandstone is formed due to the availability of silica deposits from the source rock. Limestones are formed due to the accumulation of lime content. Shale formation is due to the accumulation of clay content.
- **Transportation:** Transportation of weathered sediments depends on such means as flowing water, wind, glaciers, etc If the weathered rock fragments deposit at or near the site of the original rock, this results in the formation of gravels, pebbles, cobbles, etc. If eroded, rock fragments travel for a long distance, the fragmented rock becomes rounded, loses its Size and forms smaller and smaller grains.
- **Deposition:** Depositional environment plays an important role in the formation of sedimentary rocks. Weathered transported material is deposited on ocean floors, riverbeds, lakebeds, etc.

Size

Various terms are adopted by sedimentary petrologists.

Coarse	Gravel
Medium	Sand
Fine	Clay

Classification of Sedimentary Rocks

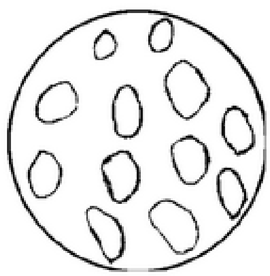
Sedimentary rocks are broadly classified on the basis of the size and origin of sediment. Five groups are recognised:

- Rudaceous
- Arenaceous
- Argillaceous
- Calcareous
- Carbonaceous deposits

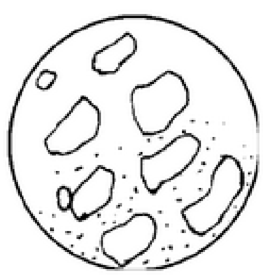
Rudaceous Deposits

Rocks consisting mainly of gravel, pebbles, cobbles or boulders and cemented materials of conglomerate and breccia belong to this group.

Conglomerate: Loosely cemented heterogeneous materials consisting of boulders, cobbles and pebbles are called a conglomerate. C train si/e is generally rounded to subrounded (see figure.



Breccia: Breccia is the name given to coarse cemented angular fragments (see figure). The composition is heterogeneous. Breccia is also formed due to the crushing of rocks along fault zones called fault breccia. Some breccias formed due to cementation of volcanic fragments are called volcanic breccia.



Occurrence: Conglomerates and breccias occur in sedimentary rocks in the Vindhyas, Kurnool systems.

Uses: *Diamonds* occur in conglomerate beds, separating different series at *Panna* in Madhya Pradesh and Wajrakarur region in Anantapur, Andhra Pradesh.

Arenaceous Deposits

Rocks mainly consisting of sandy material belong to this group. Most of the sands are composed of quartz and other loose sediments.

The sediment's origin depends on its sources. Roundness or angularity of the sand grains depends on the degree of weathering and transportation. Other important minerals that occur along with sand are feldspars, apatite, garnet, zircon, tourmaline and magnetite. These minerals are derived mainly from igneous and metamorphic rocks. These deposits occur in beach sands, river sands, etc. Along the west coast of India, in the Kerala and Konkan coasts in particular, large quantities of heavy minerals, zircon and thorium are found.

Sandstones

Weathered sand sediment after natural compaction converts into sandstone. The composition of a sedimentary rock is dependent on its cementing materials and compaction of the source rock material from which the sediment is derived. Sedimentary rocks show sedimentary features, such as ripple marks and graded bedding. Sedimentary rocks are formed in oceans, lakes or river-beds and estuaries, etc. Sandstones are formed in layers. Hence, they are commonly referred to as layered rocks. They are formed as bedding planes.

Varieties of sandstone

Sandstone is classified on the basis of its cementing material and percentage of mineral composition.

Ferruginous sandstone: A red or brown sandstone. These colours are due to the presence of ferruginous material which acts as a cementer.

Siliceous sandstone: Sand grains are cemented with grains of quartz. Thus, this sandstone is very hard in nature.

Calcareous sandstone: Sand grains are cemented with calcareous material. They are weak due to the cementation material.

Argillaceous sandstone: Celay materials are bound with sand grains as the cementing material. Such rocks are very weak and soften with water.

Arkose: Sandstone consisting of 60 per cent quart/ and 30-34 per cent feldspars is called ARKOSE. This is typically a coarse-grained rock.

Occurrence

The Vindhyan system consists of calcareous and arenaceous sandstone. The said Vindhyan system occupies a large basin extending from Dehri to Hoshangabad and from Chittoragarh to Agra and Gwalior.

Sandstone, which has a pleasing colour and is workable and durable, is extensively utilised as building stones. These workable deposits are found in Kota, Dholpur, Bundi, Jaipur, Bikaner, Bharatpur in Rajasthan and other localities in Uttar Pradesh. Long rocks are used in columns and beams. Red sandstone was used in the construction of the Red Fort in Delhi, the mosques at Agra and Lahore. Fatehpur Sikri was also constructed with red sandstone.

Oil and gas deposits also occur in the sandstones of Cauvery and Godavari basins. Extensive exploration is in progress.

Gondwana coal deposits are mainly associated with sandstone.

Argillaceous Deposits

Shale sediments are the most abundant in nature. Argillaceous deposits, clay and shales in particular, are used tor bricks, building and roofing tiles, etc.

Clay has been defined as a natural plastic earth material, mainly composed of hydrous aluminium silicates sizes of which are less than 0.002 mm.

Shale is a laminated rock. Silt is the material which is between 1/16 mm and 1/256 mm in diameter.

Types of Shale: (a) Residual day (b) Common shale (c) Red shale and mudstone (d) Black shale (e) Miscellaneous shale.

Occurrence and Uses: Shales occur in the Cuddapah system as rock. Rocks of the (Cuddapah system occur in a large area in Andhra Pradesh.

Calcareous Deposits

Limestones mid Dolomites: Limestone is a very common sedimentary rock. It has been estimated that limestone and dolomite form one-fifth to one-fourth of the stratigraphic records.

Limestones

Limestone consists essentially of calcium carbonate with magnesium carbonate and siliceous matter. The average chemical composition of limestone shows 93 per cent $CaCO_3$ and $MgCO_3$, and 5 per cent SiO_3.

Limestone is mainly formed due to the accumulation of carbonate detritus.

Limestones are classified on the basis of the presence of carbonates: siliceous limestone, argillaceous limestone, ferruginous limestone and bituminous limestone.

Limestones are useful in building stones. Crushed limestone is used in concrete aggregate and road metal. Lime is extracted from calcinization of limestone.

In the Cuddapah system, limestones are associated with the Papaghani series, Vempalli limestone stage. Limestones also occur in the Vindhyan system rocks and Kurnool system.

Carbonaceous Deposits

Deposits which are formed by the accumulation of organic materials are included in this group. These are coal, peat, lignite, anthracite and cannel coal. All these rocks consist of plant debris in various stages of alteration.

Peat: It is derived from compressed mosses and plants. It has a high ash content and smoke when burnt. Peat is not completely transformed coal. However, it is considered the first stage of coal formation.

Lignite: Also called brown coal, it is a low rank coal. Lignite generally retains the structure of the original wood from which it is converted.

Bituminous Coal: Bituminous coal is a higher rank of coal which is used in industries. The average bituminous coal contains 80-85 percent carbon a\~\6 shows a calorific value of 14 x 10^6 to 16 x 10^6 Joules. The semi-bituminous coals are transitional between coal and anthracite.

Most of the coal deposits in Gondwana are found in the Damodar system. Important coalfields are situated in Godavari valley, Wardha Valley, Satpura Sone Valley and Chhattisgarh, Mahanadi Valley, Palaman, Damodar Valley, Hazaribagh, Deogarh and Kajmahal.

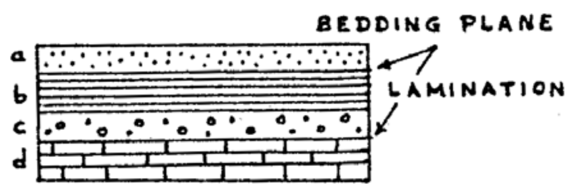
Anthracite: This is a high rank coal which consists of 90-95 per cent carbon and low oxygen and hydrogen; calorific value 15 x 10^6 J. This type of coal is *not available* in India.

Structural Features of Sedimentary Rocks

The important structural features of sedimentary rocks are stratification, lamination, graded bedding, current bedding and ripple marks.

Stratification

All sedimentary rocks are, in general, characterized by stratification. Deposition of sediments into layers or beds is called the "stratification"- The planes dividing different beds are called the "bedding planes" (see figure).

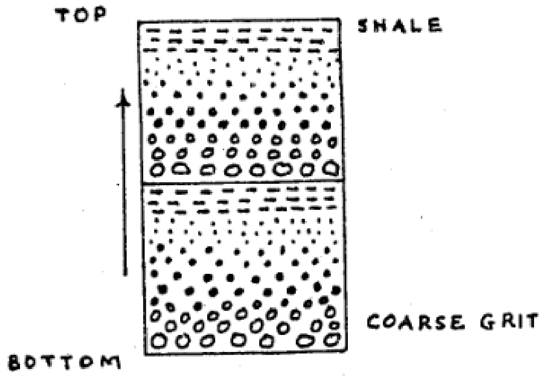


The thickness of a bed may vary from a few centimetres to many meters. Different beds are distinguished from each other by (a) difference in mineral composition, (b) variation in grain size or texture, (c) difference in colour, and (iv) variation in thickness.

Lamination

Thin bedding, less than one centimetre in thickness, are called "lamination"' (see above figure). Lamination is usually found in very fine grained rocks like shale and gives them the characteristic property of fissility. In laminated rocks, the clay and other flaky minerals tend to lie with their flat surfaces parallel to the plane of lamination. It should be noted that lamination refers to parallel arrangements of minerals within a bed whereas stratification refers to a succession of beds separated by bedding planes.

Graded Bedding. In "graded bedding" each bed shows a gradation in grain size from coarse below to fine above (see figure).



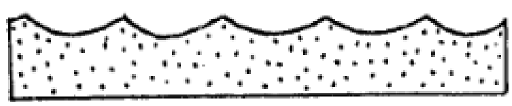
The graded bedding results from rapid sedimentation in water.

Current Bedding

Current bedding is also called the "cross bedding". In this structure minor beds or laminations lie at an angle to the planes of general stratification. These minor beds commonly terminate abruptly al the top where they are overlain by the next current bedded deposit Current bedding is commonly found in shallow water and wind formed deposits.

Ripple Marks

"Ripple marks" are the wave undulations seen on the surface of bedding planes (see figure).



They are produced by the action of waves and currents in shallow water.

Concretions

"Concretions" are variously shaped masses or nodules of mineral matter found within a sedimentary rock. Their shape may be spherical, ellipsoidal, lenticular or irregular. Concretions generally consist of calcium carbonate or silica and often possess an internal radiating or concentric structure. They are formed by the deposition of mineral matter from percolating solutions about a nucleus. Their chemical composition is generally different from the enclosing rock. They often represent a concentration of one of the minor constituents of the host rock. For example, in limestones there are concretions of flint.

METAMORPHIC ROCKS

Metamorphic rocks are pre-existing rocks formed by mineralogical, chemical or structural changes especially in the solid state, in response to marked changes in temperature, pressure and chemical environment at depths in the earth's crust, that is below the zones of weathering and cementation.

The rocks subjected to metamorphism lose their original characteristics and new features are added. For instance, granite, an igneous rock is metamorphosed to form gneiss, whereas, a sedimentary rock, limestone, is metamorphosed to form marble. In weathering conditions, these metamorphic rocks again form sedimentary rocks.

Based on the worldwide geological map statistics of the abundance of rocks established on the surface of the earth, igneous and metamorphic rocks occupy 34 per cent and sedimentary rocks 66 per cent.

The term *metamorphism* is derived from Greek, **meta** (signifying change) and **morphe**, shape. Metamorphism thus denotes the transformation of rocks into new types by the recrystallisation of their constituents. In the metamorphic process, most minerals are completely or partially recrystallised within the rocks and new textures and structures are formed. The changes which occur in metamorphism are due to temperature and pressure conditions in the crustal layers of the earth. Generally, original igneous rocks, sedimentary or metamorphosed rocks also are transformed into new recrystallised rocks due to temperature and pressure conditions.

Agents of Metamorphism

The process of metamorphism is mainly due to three factors; (a) temperature (b) pressure (c) chemically active fluids. Metamorphism takes place at the crustal layers of the earth. The temperature increases in the deeper zones of the crustal layers.

The pressure developed due to gravity results in hydrostatic pressure, which prompts changes in the volume of the rocks. This in turn develops non-uniform pressure, which changes the shape of the rock constituents.

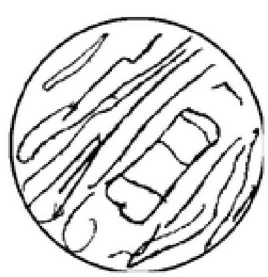
Chemically active fluids are the most important factor in metamorphism. Fluid occupies void spaces and fissures. Water, carbon dioxide and volatile matters present in the magma influence the rock particles.

Structure of Metamorphic Rocks

Classification of metamorphic structures into five groups: cataclastic, maeulose, schistose, granulose and gneissose.

Cataclastic

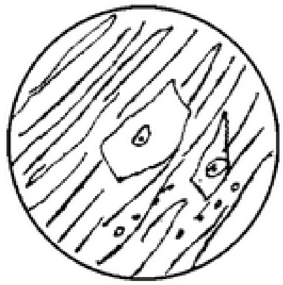
A cataclastic structure develops due to the breakdown of fragmental rocks, mainly as a result of shearing action (see figure).



This causes soft rocks, such as shale to shatter and get crushed to form crushbreccia, which forms mylonite at a later stage. In some instances more resistant minerals undergo less crushing while in other cases less resistant minerals undergo severe deformation and form a porphyrorlastic structure. This texture is typically exhibited by cataclasite and mylonitc.

Maculose

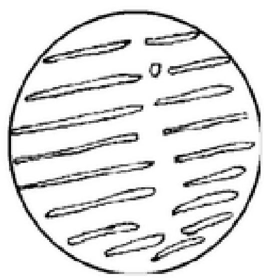
In some metamorphic works, porphyroblasts of resistant minerals, such as cordierite, andalusite and biotite are developed and in some varieties spotting is visible due to incipient crystallization of these minerals and segregation of carbonaceous matter (see figure).



Maculose texture is typically exhibited in argillaceous rocks under thermal or contact metamorphism.

Schistose

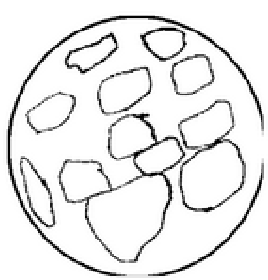
A schistose structure is typically exhibited by schist rocks. These rocks show more or less parallel bands (see figure).



Flaky minerals, such as biotite, hornblende and talc are influenced by the temperature and pressure conditions and form parallel layered arrangements resulting in a schistose structure.

Granulose

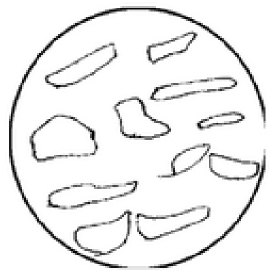
A granulose structure is formed due to the presence of subhedral grain minerals, such as quartz, feldspar, pyroxene, calcite, etc. A granulose texture exhibits more or less a uniform grain size (see figure).



Marble and quartzite rocks exhibit a granulose texture.

Gneissose

A gneissose structure is formed due to the alteration of schistose bands and granulose structure. A gneissose structure is not parallel, hence, it exhibits a dissimilarity in nature (see figure).



A gneissose texture is exhibited by rocks, such as granite gneiss and hornblende gneiss.

Classification of Metamorphic Rocks

Throe major classes of metamorphism are identified on the basis of temperature and pressure. They are:

- Contact/Thermal metamorphism: In this process, rise of temperature is the dominant factor. Thermal effects are influenced by the contact zones of country rocks of igneous or sedimentary types, which are down folded into hotter zones in the crustal layers.
- Regional metamorphism: In this process, both temperature and pressure affect a large regional area.
- Dynamic or dislocation metamorphism: In this process rock stress is the dominant factor, as in shearing belts.

Contact Metamorphism

During contact metamorphism, it' the contact bordering zone is a granite rock mass intruded into a sedimentary rock, the latter is metamorphosed to some distance from the contact area. For instance, sandstone is converted into quartzite and limestone into marble.

Regional Metamorphism

Regional metamorphism develops under the hydrostatic pressure rising from the weight of overlying rocks. It results in the origin of shearing stresses. The grade of metamorphism increases with depth. Increasing temperatures are associated with stress conditions. In the epizone, low temperature, high shearing stresses originate. In the mesozone, moderate temperature and pressure occur. In the deeper katazone, stress develops with temperature.

These conditions favour conversion of sedimentary rocks of argillaceous composition into slate or schist or gneiss.

Plutonic Metamorphism

At great depths below the earth's surface, static pressures and high temperatures operate together. The metamorphism caused by these factors is called the "**plutonic metamorphism**". High static pressure favours reduction in volume. Hence during recrystalization mainly denser minerals are formed. The metamorphic rocks produced in this way commonly have an even grained texture. Such rocks are called "*granulites*".

Metamorphic Rock Types

Slate

Nature. Slates are dark coloured exceedingly fine grained low grade metamorphic rocks. They have a remarkable properly called slaty cleavage which permits them to be split into thin broad sheets. Their colour is commonly gray to black but may be green, yellow, brown and red.

Mineral Composition. Slates are composed of a very fine grained mixture of micas and chlorite with some quartz and felspar.

Texture and Structure. Slates are very fine grained rocks which show slaty cleavage.

Origin. Majority of slates are formed by the dynamic metamorphism of shales. Their characteristic slaty cleavage may or may not be parallel to the bedding planes of the original shales.

Phyllite

Nature. A phyllite is a fine grained, foliated lustrous rock.

Mineral Composition. It consists of chlorite, muscovite and quartz. The grains of this rocks are so fine that individual minerals can not be recognized by unaided eye.

Texture and Structure. It is a fine grained rock showing foliated structure. It splits along foliation planes with an uneven surface.

Origin. Phyllites are formed due to dynamo thermal metamorphism of shales. They represent an intermediate stage of metamorphism between slate and schist.

Schist

Nature, Schists are coarse grained metamorphic rocks which show well developed foliation or schistosity along which the rock may be easily broken. Their colour varies according to mineral composition. Mica-schists are the most common metamorphic rocks.

Mineral Composition. Mica-schists consist essentially of quartz and mica, usually muscovite or biotite. Mica is the major mineral which occurs in irregular leaves and foliated masses.

Varieties. Besides mica-schists, there are various other kinds of schists which are chiefly derived by the metamorphism of the basic igneous rocks. The most important types are "talc-schist",, "chlorite-schist", "hornblende-schist" and "amphibolite". These are characterized, as their names indicate, by the abundance of some metamorphic ferromagnesian mineral.

Texture and Structure. Schists are coarse grained rocks having a prominent schistose structure. They split easily into thin sheets along the planes of schistosity.

Origin. Schists are generally the product of regional metamorphism.

Gneiss

Nature. A gneiss is a coarse grained, irregularly banded metamorphic rock having poor schistosity. A gneiss has usually a light colour, although this is not necessarily so.

Mineral Composition. Quartz and felspar occur together in light coloured bands which alternate with dark bands of flaky ferromagnesian minerals, such as biotite or hornblende. Generally quartz and felspars predominate over micaceous minerals.

Varieties. There are many varieties of gneiss having varied mineral associations. They are named generally according to the dominant ferromagnesian mineral present, such as "biotite-gneiss" and "hornblende-gneiss".

Texture and Structure. Gneisses are coarse grained rocks having gneissose structure.

Origin. Gneisses are more commonly derived by the high grade regional metamorphism of igneous rocks, mostly granites. They may also be formed from sedimentary rocks.

Quartzite

Nature. A quartzite is a hard, dense, siliceous metamorphic rock hiving .granular texture. It is distinguished from a sandstone by noting the fracture which in a quartzite passes through the grains but in a sandstone passes around them.

Mineral Composition. Quartzites are composed essentially of quartz with small amounts of mica, tourmaline, graphite or iron minerals. They are usually light in colour.

Texture and Structure. A quartzite is a compact rock of interlocking quartz grains. Its structure is granulose. This rocks breaks with a rough fracture surface.

Origin. Quartzites are derived from sandstones by high grade metamorphism.

Marble

Nature. A marble is a crystalline calcareous metamorphic rock having granular texture. Marbles are generally while but various impurities may create a wide range of colour such as pink, yellow, grey, green and black.

Mineral Composition. A marble is composed of grains of calcite or more rarely dolomite.

Texture and Structure. The marbles show granulose texture. The individual grains may be so small that they can not be distinguished by the eye or they may be quite coarse and show clearly the characteristic calcite cleavage.

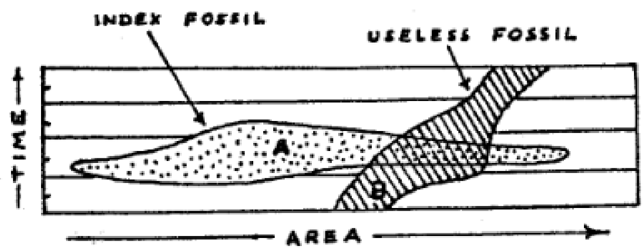
Origin. Marbles are formed as a result of metamorphism of limestones.

Stratigraphy

"**Stratigraphy**" is the science of description, correlation and classification of strata in *sedimentary* rocks. It also includes the interpretation of the dispositional environments of the strata.

Facies. A set of lithological and paleontological characteristics of a sedimentary rock which indicate its particular environment of deposition, are called "facies". A lateral variation in lithology and fossil assemblage in a formation which result from change in the environment of deposition, is called "facies variation". For example, a formation may be composed of shale in one locality and limestone in another or fresh water fossils at one place and marine fossils at another. For a metamorphic rock the term fades means the particular range of pressure and temperature under which the rock crystallized.

Index fossils. Those fossil forms which have short time ranges of their existence and wide geographical distribution, are called "index fossils". In following figure the fossils 'A' have wide distribution and short duration, and therefore they are the index fossils.



The fossils 'B' are not index fossils because they have long time ranges and limited distribution. The index fossils are an excellent tool for correlating the fossiliferous rock formations of the same age.

PRINCIPLES OF STRATIGRAPHY

There are three major principles which are used to determine the relative ages of strata. These principles are as follows.

Law of Superposition

In a series of undisturbed beds, a bed that overlies another bed is always the younger. The youngest bed will be at the top of the sequence.

Fossil Content

Each of the sedimentary beds contain a particular set of fossils by which it can be identified. Because the lower forms of life existed long before the higher organism appeared, it is possible to assign relative ages to the strata containing fossils.

Lithological Character

A sedimentary bed may be indentified by its distinct lithological character. But as similar rock beds are known to occur in formations of widely different geological ages, the lithology is not of much use for determining relative ages.

PRINCIPLES OF CORRELATION

The rock formations of widely separated areas are correlated with the help of the following criteria.

Lithology

Correlation by means of lithology is not reliable because a rock bed when traced laterally may change its character. Further similar rock beds are known to occur in formations of widely different geological ages.

Fossil Content

Fossiliferous rocks are characterized by the presence of distinct and definite set of fossils in them. However, just as the beds show lateral variation in the lithology, they may also show lateral variation in the fossil assemblage. Hence only index fossils are used for correlation purposes.

Unconformities

The unconformities are of great significance in classifying and correlating rock formations. The unconformities represent breaks in depositional sequence hence they are significant in the interpretation of the geological history. For example, an angular unconformity is a surface of erosion that separates two sets of beds whose bedding planes are not parallel. It suggests that first the lower set of beds was formed in the horizontal disposition. This set was deformed and then eroded to a more or less even surface before the upper set was deposited horizontally upon it.

Metamorphism

In a particular area, the older rocks may show higher grade of metamorphism as compared to the younger rocks.

Igneous Intrusion

The igneous history of a particular region may be identical to another region. In such cases rocks can be correlated.

Radiometric Dating

The age of intrusive igneous bodies may be determined by the radiometric methods and then the correlation may be done.

FOSSILS

"Fossils" are remains or impressions of ancient animals and plants which have been preserved within the sedimentary rocks.

Conditions of Preservation

All the animals and plants are not preserved as fossils. The two most important conditions which favour the preservation of fossils are :

- possession of hard parts, and
- Immediate burial

Possession of Hard Parts

After the death of the organisms, the soft parts are generally easily decomposed. Therefore animals like jelly fish and insects which are totally composed of soft parts, are not ordinarily preserved as fossils. The animals which possess hard skeleton have a better chance of being converted into fossils-Immediate Burial. If the animals and plants are not buried quickly after their death, they are likely to be destroyed by chemical decay and other agencies of erosion.

Immediate Burial

If the animals and plants are not buried quickly after their death, they are likely to be destroyed by chemical decay and other agencies of erosion.

Uses of Fossils

- The fossils are commonly used for correlating the strata and determining their relative ages.
- Fossils indicate whether the rock is a fresh water deposit or a marine deposit.
- Fossils give information about the climate of the times in which they lived.
- The fossils have helped in understanding the evolution of plants and animals.

LITHOSTRATIGRAPHIC CLASSIFICATION

In regions having different kinds of geological history, the boundaries of the Geological Time Scale do not coincide with the actual stratigraphic boundaries. In many areas, though the major stratigraphic divisions are identified, the demarcation of smaller divisions, such as series and stages become very difficult. In case of unfossiliferous strata, it is not possible to identify the divisions corresponding to those of the standard time scale. In order to avoid these difficulties the "Lithostratigraphic classification" has been devised. In this classification the reformations are divided chiefly on the basis of lithological criteria.

Group

The major divisions of rock formations are called "Group." Each Group includes a thick succession of rocks which extends over a large area. The bigger unconformities separate one Group from another. A "Supergroup" is formed when two or more Groups join together;

Formation

It is the basic unit used for naming the rocks in stratigraphy. It may be defined as a set of rocks which have some distinctive feature of lithology and are large enough to be mapped.

Bed

A bed is the smallest lithological unit. It may be defined as a single sedimentary rock unit which has a distinct set of mineralogical or fossil characteristics which help to distinguish it from beds above and below.

STRATIGRAPHIC UNITS IN INDIA

Peninsular India

The Peninsular India is primarily made up of rocks of the Archaean and Precambrian age. The Archaean rocks have been metamorphosed to varying degrees. In addition there exists the Deccan traps and Rajmahal traps of Jurassic to Eocene age. Post Cambrian sedimentary rocks occur in the Gondwana basin and occasionally along the coastal tracts of the Peninsular India.

Indo-Gangetic Plain

The Indo-Gangetic Plain is chiefly made up of sands and clays of Pleistocene and Recent age. The basement of the Punjab shelf is made up of the Precambrian rocks, while that of the east and west U.P. shelves contain Precambrian and Vindhyan rocks. The Bengal shelf is believed to contain rocks of Gondwana age and Rajmahal traps.

Extra Peninsular India

The rock formations of the Extra Peninsular India have been disturbed greatly by the complex folding, faulting and over thrusting. The Extra-Peninsular India has been subdivided into four longitudinal geomorphic zones: (i) Himalayan zone, (ii) Central crystalline zone of the Higher Himalaya (iii) Lesser Himalayan zone (iv) Foredeep folded belt.

Mineralogy

The science of mineralogy is the study of the physics and chemistry of natural, solid, crystalline materials. A mineral is a naturally-occurring, homogeneous solid with a definite, but generally not fixed, chemical composition and an ordered atomic arrangement. It is usually formed by inorganic processes.

MINERAL PROPERTIES IN HAND SPECIMEN

Learning to recognize hand specimens of approximately 100 of the most common rock-forming minerals is an important part of this course. This recognition is based on seven easily examined properties plus a few unique properties such as magnetism or radioactivity that are strong clues to a mineral's identity. These seven properties are:

- Crystal form and habit (shape).
- Lustre and transparency
- Color and streak.
- Cleavage, fracture, and parting.
- Tenacity
- Density
- Hardness

MINERAL OCCURRENCES AND ENVIRONMENTS

In addition to physical properties, one of the most diagnostic features of a mineral is the geological environment in which it is occurs. Learning to recognize different types of geological environments can be thus be very helpful in recognizing the common minerals. For the purposes of aiding mineral identification, we have developed a very rough classification of geological environments, most of which can be visited locally.

- Igneous Minerals.
- Metamorphic minerals.
- Sedimentary minerals.
- Hydrothermal minerals.

CLASSIFICATION OF ORE DEPOSITS

The ore deposits are formed in many different ways. Depending upon the process that may operate to produce them, the ore deposits may be classified as follows.

- Magmatic ore deposits.
- Sublimation ore deposits.
- Pegmatitic ore deposits.

- Contact metasomatic ore deposits.
- Hydrothermal ore deposits. (i) Cavity filling deposits, (ii) Replacement deposits.
- Sedimentation ore deposits.
- Evaporation ore deposits.
- Residual and mechanical concentration deposits.
- Oxidation and supergene enrichment deposits.
- Metamorphic ore deposits.

Magmatic Ore Deposits

The magmatic ore deposits are the magmatic products which crystallize from magmas. They have close relationship with the intrusive igneous rocks. The magmatic ore deposits can be classified as follows:

Early magmatic deposits

Early magmatic deposits are formed during the early stages of the magmatic period. In this case the ore minerals crystallize earlier than the rock silicates. The minerals of nickel, chromium and platinum are usually found as early magmatic deposits. The early magmatic deposits can be

- *Dissemination deposits* When a magma crystallizes under deep scaled conditions, a granular igneous rock is formed. In such a rock early fanned crystals of ore minerals may occur in dissemination. Here grains of ore are found scattered more or less evenly throughout the rock mass. Hence the whole rock mass constitutes the ore deposit. The dissemination deposits occur in the shape of a dyke, pipe or small stock-like mass.
- *Segregation deposits* Early magmatic segregation deposits are formed as a result of gravitative crystallization differentiation. In such cases, the ore minerals which crystallize early, get concentrated in a particular part of the igneous mass. The ore deposits thus formed are called "segregation."

Late magmatic deposits

The ore deposits which are formed towards the close of the Magmatic period are called "late magmatic deposits". The late magmatic deposits contain those ore minerals which have crystallized at rather low temperature from a residual magma.

- *Residual liquid segregation.* Residual Liquid Segregation. In a magma, particularly the basic magma which is undergoing differential ion, the residual liquid may become enriched in iron and titanium. This heavy residual liquid may segregate and crystallize within the parent igneous mass.

- *Residual liquid injection*. The iron rich residual liquid accumulated as a result of differentiation of mafic magma, may get injected into die surrounding country rocks.
- *Immiscible liquid segregation.* When a mafic magma cools, the sulfide rich immiscible liquid separates out and accumulates at the bottom of the igneous body. This separation is similar to that of oil and water.
- *Immiscible liquid injection*. The sulfide rich immiscible liquid which separates out during the differentiation of mafic magma, may get injected into the enclosing rock. On consolidation it forms the "immiscible liquid injection deposit."

Sublimation Deposits

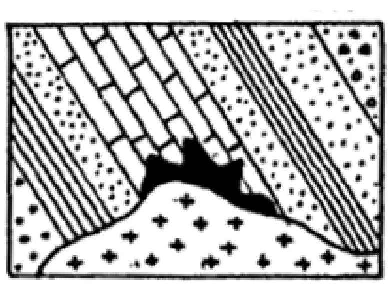
Sublimation is a very minor process of formation of ore deposits. Sublimation deposits contain only those minerals which have been volatilized by heat and subsequently redeposited in the same form at low temperature and pressure.

Pegmatitic deposits

The late residual magma which is left in the last stage of crystallization, commonly contains silica, alkalies, water, carbon dioxide and concentrations of rare elements and metals. Pegmatites are formed when this residual magma gets injected into the enclosing rocks.

Contact Metasomatic Deposits

Where certain igneous rocks invade carbonate rocks, such as limestones, ore deposits are formed near the contact by the reaction of the magmatic vapours on the host rocks (see figure).



These reactions take place under conditions of high temperature and pressure. The new minerals that develop may be composed of partly or wholly of the constituents added from the magma.

Hydrothermal Deposits

The epigenetic ore deposits formed by hydrothermal solutions are called "hydrothermal ore deposits". The ore deposits which are commonly formed by the hydrothermal process are of gold, silver, copper, lead, zinc and mercury.

Hydrothermal Solution. The fluid left during the later stage of crystallization of intrusive magma when the main rock forming minerals have already been precipitated, is called "*residual fluid*". Metals originally present in the magma, concentrate in this fluid. This fluid which is a hot watery solution containing mineralized liquids derived from an intrusive magma, is called "hydrothermal solution".

The hydrothermal solution move through cracks and openings present in the rocks and deposit their dissolved minerals there. Minerals which have lowest temperatures of crystallization may migrate very far away while those having higher temperatures of crystallization.

Sedimentation Deposits

Sedimentation deposits are the syngenetic ore deposits which are formed at the same time as the enclosing rock. They occur as beds in the sedimentary rocks. Some of the important sedimentation deposits are iron-ore, manganese ore, copper ore, phosphates, limestone, coal, and clays. These deposits are formed by the process of sedimentation.

This process may be summarized as follows:

- During weathering, the materials are released from the source rock. In this process the valuable mineral constituents are taken into solution. The chief solvents are carbonated water, organic acids and sulphate solutions.
- Most of the valuable substances are transported either in suspension or in solution by means of river water to the sea.
- In the sea, the valuable material is deposited mechanically, chemically or biochemically. The chemical precipitation of materials in solution is controlled largely by the pH and Eh of the environment The pH is responsible for the acidic or alkaline conditions and the Eh for the oxidation-reduction potential.

Evaporation Deposits

Many non metallic mineral deposits are formed as a result of evaporation of shallow and isolated bodies of saline water. The chief minerals which occur as evaporation deposits are common salt, gypsum, and other salts of K, Na, Ca, and Mg.

The process of evaporation may briefly be summarized as follows.

(i) The main source of the evaporation deposits is sea water.

(«) When a body of sea water is cutoff during oscillations of land and sea its water evaporate. This leads to the concentration of soluble salts.

(iii) When supersaturation of a salt is reached, that salt is precipitated and thus cv.^^ ;;.,mi deposits are formed.

COAL

Coal is the world's leading mineral fuel. It is burned to produce heat which is used to generate electric power. The coke which is made by heating coal to a very high temperature in the absence of air. is used in the metallurgical industry.

The term "coal" covers a wide variety of materials, ranging from **lignite** at one hand to **anthracite** on the other. It may be defined as a solid stratified rock composed mainly of carbonised plants.

Ranks of Coal

The process of conversion of vegetable matter to coal involves loss of oxygen and hydrogen, and concentration of carbon. The chief stages of coal formation are :

- peat,
- lignite,
- bituminous coal
- anthracite.

Peat is not a coal though it is fuel. The "Rank" of a coal is its position in the lignite-anthracite series. From lignite to anthracite there is a progressive elimination of water, oxygen and hydrogen and an increase in carbon. In coals carbon occurs in two forms :(i) as fixed carbon, and (ii) as volatile matter. The ratio of these two (fuel ratio) determines the rank of coal.

Classification of Coal

On the basis of rank and quality, the coals are classified into four main groups :

- lignite,
- bituminous coal,
- anthracite, and
- cannel coal.

Peat lies above lignite and graphite below anthracite.

Lignite

Lignite is also called "brown coal" as its colour is often dark brown. It represents the second stage in coal formation. The lignite is composed of finely divided plant tissues. It contains about 25-45% moisture. Because of high water content, it shrinks, cracks and often disintegrates when dried in air. The lignite bums freely with a long smoky flame and has a low calorific value (11000 - 12500 B.T.U.).

Bituminous Coal

It is a dense coal of black colour. It shows banded structure in which dull and bright bands alternate. The bituminous coal breaks parallel to bands but the presence of vertical joints makes it to give cubical or rectangular blocks. Its moisture content is low, volatile matter medium and fixed carbon high. It burns easily with a smoky yellow flame. Its calorific value ranges between 13500 to 16000 B.T.U.

Anthracite

It is a hard coal with an iron-black colour and sub metallic lustre, it does not soil the fingers and commonly breaks with a conchoidal fracture. The anthracite contains about 92 - 94% carbon and 3 - 8% volatile matter. It is difficult to ignite but burns with a short blue flame and gives little smoke. Its calorific value ranges between 15000 to 15600 B.T.U.

Banded Constituents of Coal

In banded coals four separate kinds of coal constituents have been recognised:

- vitrain,
- clarain,
- durain, and
- fusain.

Vitrain

Vitrain forms thin bright glassy bands of coal which are up to half centimetre thick. It is very brittle and breaks with a conchoidal fracture. The woody structure is not visible with naked eye. Vitrain is a coking constituent of coal.

Clarain

Clarain forms thin bands in coal. It is characterized by bright colour and silky lustre. It is composed largely of attritus. Am it us is the finely divided plant residue which is composed of the more resistant plant products. Clarain is a coking constituent of coal.

Durain

The dull earthy looking bands of coal are called durain. Durain is hard and compact, and has granular texture. Its colour is lead-gray. It consists of cuticles, spores, etc. Durain is the noncoking constituent of coal.

Fusain

Fusain is also called "mineral charcoal". It is a soft, powdery, pitch black substance which soils the fingers. It is a minor constituent of coal which occurs in small patches and in the body of durain and clarain. Fusain is high in ash and is a noncoking constituent.

Origin of Coal

Coals are sedimentary rocks formed by accumulation of plant materials in swamps. Hence the source material of coal is the vegetation matter. The formation of a coal deposit requires a large accumulation of vegetation matter. This implies large vegetation growth which is possible only in subtropical climate with heavy rainfall well distributed throughout the year.

There are two theories to explain the mode of accumulation of plant materials to give rise to coal seams :

- the in-situ theory, and
- the drift theory

In-situ Theory

The in-situ theory suggests that the vegetation matter had accumulated at the place of growth itself in the swamps. This means that the forests grew at the same place where we now find coal seams. The in-situ theory may briefly be summarized as follows.

- The vegetable matter was accumulated in the coal forest itself.
- As the land was sinking slowly, the accumulated plant material was kept saturated with water and therefore it was not decomposed and destroyed.
- In the course of time, the rate of sinking of land was increased and the coal forest was submerged under water. This resulted in the geological burial of the vegetable matter below sand and mud layers.
- Then uplifting took place and the land emerged out of water. The coal forests came into existence again and the above said cycle of coal formation was repeated. In this way alternation of strata and coal seams were formed.

Drift Theory

This theory suggests that the plant material was transported by stream action from their place of growth and deposited at suitable places in lakes or sea just like other sediments.

The coal seams of India are of drift origin. The drift theory may briefly be summarized as follows.

- The plant material from the coal forest was transported by water and deposited in lakes or sea just like other sediments.
- During transportation the various materials were sorted out as usual, in accordance with their specific gravities.
- The pure coal seam was formed in places to which only the lightest material (plant material) had access.
- A stream with shale bauds was formed in places where a temporary change in the water currents and hence the nature of sediment occurred.
- Rapid and frequent oscillatory earth movements had given rise to several coal seams one above the other separated by sediments.

Formation of Coal

The Plant materials were accumulated in swamps, broad deltas, coastal plain areas and interior basins. The climatic conditions (hat favoured large accumulation of plant material were mild temperate to subtropical. The transformation of plant material into coal consists in the *progressive enrichment* of carbon content.

Preservation

The land sank slowly with the accumulation of the plant material. Thus the plant material was kept saturated with water. The water or the reducing environment protected the plant material from oxidation and therefore it was not decomposed and destroyed.

Biochemical Change

When plant material falls into water, the decay starts. But it stops soon as the reducing environment and the lack of oxygen prevents further decay. In this process the less resistant parts of the plants such as cellulose and starches are decomposed by the bacterial action and the resistant parts such as wax, resin, along with woody fragments sink to the bottom of the swamp. Thus the partly decomposed plant debris accumulates and it gradually turns into "*peat*".

Carbonization and Metamorphism

With the passage of time peat changes slowly into anthracite. In this process mainly chemical changes take place. These changes are brought about by the increase in the pressure and temperature which is caused due to deep burial. Form peat to anthracite the amount of oxygen goes on decreasing and the amount of fixed carbon goes on increasing.

The change in the rank of coal is largely a result of pressure and time. The older the coal, the greater the depth of burial. Thus with the passage of time, there is increase in the pressure which accelerates metamorphism and turns peat into lignite, bituminous coal or anthracite.

Occurrence of Coal

About 98% of the coal produced in India comes from the rock formations of Permo-Carboniferous age, that is Lower Gondwana system, while the rest is obtained from the tertiary rocks. The coal found in the Lower Gondwana rocks are of bituminous type whereas those found in the tertiary rocks are lignites.

Most of the Gondwana coals are noncoking bituminous coats. The coking coals are found only in Jharia, Girdih and Bokaro coal fields. The reserves of all types of coal occurring within a depth of 600 meters are estimated at 120,000 million tonnes. The reserves of coking coals are about 20,000 million tonnes. The reserves of lignite deposits are estimated to be about 3500 million tonnes. The deposits of lignite occur mainly in the tertiary rocks of Kashmir valley, Assam, Madras(Neyveli) and Rajasthan(Palana).

Lower Gondwana Coal Fields

The Lower Gondwana coal fields of India are situated chiefly in river valleys.

- Damodar Valley Region. Coal fields of West Bengal and Bihar.
- Son-Mahanadi Valley Region. Coal fields of Madhya Pradesh and Orissa.
- Wardha-Godavari Valley Region. Coal fields of Andhra Pradesh and Maharashtra.

GOLD

The gold is a precious metal. Its main use is for currency. It is stereo as bullion to back up in value the paper currency. Large quantity of gold is also required for the manufacture of jewellery.

The chief mineral of gold is "native gold". In nature, native gold is generally found mixed with some silver, ft is usually associated with some metallic sulphides, such as pyrrhotite and iron-pyrite.

Types of Deposits

Hydrothermal Deposits

The gold deposits are generally of high temperature hypothermal origin. The ore occurs as lodes, veins or gold bearing quartz reefs in igneous, sedimentary or metamorphic rocks.

Placer Deposits

The gold also occurs as placer deposits in stream beds or on sea shores.

Origin

In India economic deposits of gold are found only in "Kolar gold field" and "Hutti gold field" of Karnataka. Here gold occurs as gold bearing quartz veins in hornblende-schists, greenstones and amphibolites of Dharwar system. These gold deposits are believed to be of high temperature hypothermal origin. The mineralization is generally controlled by shear zones and faults-which strike roughly in the N-S direction.

Iron Ore

The iron ore is the second largest mineral wealth of India, the coal being on the top. The possible reserves of high grade iron ore are about 17,630 million tonnes of hematite and 1610 million tonnes of magnetite.

Iron is the backbone of modern civilization. Iron ore is chiefly used in the iron and steel industry. Iron is used for making machine, automobiles, trains, ships etc.

The chief ore mineral of iron is hematite (Fe_2O_3).

Types of Deposits

Magmatic Deposits

Deposits of magnetite and titaniferous magnetite may occur as magmatic deposits in some basic igneous rocks.

Contact Metasomatic Deposits

The magnetite may occur as contact metasomatic deposits is some limestones.

Replacement Deposits

Deposits of both magnetite and hematite may occur as replacement deposits in limestones.

Sedimentary Deposits

Deposits of hematite, limonite and siderite may occur as beds in sedimentary rocks.

Residual Deposits

Deposits of high grade hematite, magnetite and limonite may also occur as residual deposits.

Origin

Almost all the major Indian iron ore deposits are of sedimentary and residual origin. They occur in the rocks of the Iron-Ore series (Archaean) and their equivalents. They are closely associated with the banded-hematite-quartzites and are derived from them.

The banded-hematite-quartzites are of sedimentary origin. This rock contains about 28-30% iron. Subsequently the silica of this rock is removed by leaching and the concentrated iron ore is left behind to form residual iron ore deposits. These deposits occur in beds which are up to 40 meters thick. The iron ores consist of massive, laminated and powdery hematite containing 60-69% iron.

Distribution

- Bihar and Orissa
- Madhya Pradesh and Maharashtra
- Goa
- Karnataka
- Tamil Nadu

MANGANESE ORE

Of all the metals used in steel alloys, manganese is the most important. Manganese is mainly used in making high manganese steels and carbon steels. The manganese steel is used where hardness and toughness are desired, e.g. in the manufacture of armour plate, car wheels, safes, crushers, machine tools etc.

The principal ore minerals of manganese are pyrolusite (MnO_2), manganite ($Mn_2O_3H_2O$), wad etc. Wad is the massive earthy form of manganese oxide.

Type of Deposits

Syngenetic Gonditic Deposits

These deposits of manganese ore are found in M.P. - Maharashtra zone. They are associated with rocks of Sausor series (Archaean) including gondites.

Syngenetic Reef Deposits

These deposits are found in Orissa - Andhra Pradesh zone. They are associated with kodurite rocks. A "kodurite" is a metamorphic rock.

Replacement Deposits

These deposits of manganese ore are found in rocks of the Iron-ore series in Bihar and Orissa, and in the Dharwar rocks in Karnataka and Goa.

Lateritoid Deposits

These deposits occur within lateritic cappings and are of residual origin, Lateritoid deposits are associated with almost all the above deposits.

Distribution

- Madhya Pradesh – Maharashtra Zone
- Bihar-Orissa-Andhra Pradesh Zone
- Karnataka - Goa Zone

METALLOGENIC EPOCHS

Cycles of erosion, deposition, folding, faulting, igneous activity and ore deposition have been repeated through geologic time. These cycles of ore formation have given rise to metallogenic epochs.

Most of the mineral deposits of one type are formed in regions during definite periods in the earth's history. Such deposits constitute the "metallogenic epochs". For example, the chromite deposits found in the Archaean rocks are affiliated to ultra basic igneous rocks. They are formed in regions of crustal disturbance during period of igneous intrusion. These deposits constitute a metallic epoch.

The deposits of coal, iron ore. and manganese ore are of sedimentary origin. They are formed during periods of quiet sedimentation. Hence they also constitute metallogenic epochs. However, the ore deposits formed due to weathering, do not form any metallogenic epoch because the process of weathering has operated at all times in the earth's history.

Metallogenic Epochs of India

Archaean Period. In India, several metallogenic epochs have been recognised in the Archaean period. Periods of igneous activity and accompanying ore formation alternated with periods of sedimentation and accompanying mineral deposition. All the important deposits of Fe, Mn, Au, Cu. Ph. Zn, Cr, and mica were formed in this period. In the shield areas of India, the five main belts of Archaean rock formations are: (i) Karnataka and adjoining states, (ii) Eastern Ghat, (iii) Singhbhum-Gangpur area of Bihar and Orissa, (iv) Nagpur-Durg area of central India, and (v) Aravalli belt of Rajasthan.

In these belts the following epochs of ore formation have been recognised.

- *Sedimentary-Metamorphic Deposits*. The deposits of iron and manganese ore found in various regions in the Archaean rocks, are of sedimentary metamorphic origin.
- *Magmatic Deposits*. The Archaean rocks have been intruded by basic and ultra basic rocks which have given rise to magmatic deposits of chromite, nickel, and titaniferous and vanadiferous magnetite.

- *Hydrothermal Deposits*. The Archaean rocks contain economic ore deposits of gold, copper, lead, zinc and uranium, these hydrothermal deposits are believed to have been derived from the granitic and gneissic intrusions.
- *Pegmatitic Deposits*. The deposits of mica belong to this category.

Cuddapah Period. The main Cuddapah basin is situated in Andhra Pradesh. The important mineral deposits found in the Cuddapah rocks are copper, lead, zinc, asbestos and barytes.

Delhi Period. The Delhi rock formations occur along the Aravalli mountains in Rajasthan. These rocks contain mainly the hydrothermal deposits of copper, lead and zinc. The mineralization is caused by the acid magmatism.

Vindhyan Period. The Vindhyan rock forrnations show extensive development in central India. No major metallogenic epoch has been recognised in this period.

Gondwana Period. The Lower Gondwana rocks contain coal seams. The coal seams are formed during periods of quiet sedimentation. Hence they constitute a mineralogenic epoch.

PRINCIPLES OF ENGINEERING GEOLOGY

METALLOGENIC PROVINCES

The regions where mineral deposits of specific types are found abundantly, are called "*metallogenic provinces*". A metallogenic province may contain mineralization of more than one epoch. Examples of metallogenic provinces of India are as follows.

- **Bihar-West Bengal Area**. This area may be regarded as a coal province, as most of the coal fields of India are concentrated in this region.
- **M.P.-Maharashtra Area**. This region may be regarded as manganese province, as large deposits of manganese ore are situated in this area.
- **Karnataka**. The Kolar gold field may be regarded as a gold province.

OCEAN MINING

Natural gas and oil have been extracted from the seas for decades, but the ores and mineral deposits on the sea floor have attracted little interest. Yet as resource prices rise, so too does the appeal of ocean mining. The excavation of massive sulphides and manganese nodules is expected to begin within the next few years.

The oceans hold a veritable treasure trove of valuable resources. Sand and gravel, oil and gas have been extracted from the sea for many years. In addition, minerals transported by erosion from the continents to the coastal areas are mined from the shallow shelf and beach areas. These include diamonds off the coasts of South Africa and Namibia as well as deposits of tin, titanium and gold along the shores of Africa, Asia and South America. Efforts to expand ocean mining into deep-sea waters have recently begun. The major focus is on manganese nodules, which are usually located at depths below 4000 metres, gas hydrates (located between 350 and 5000 metres), and cobalt crusts along the flanks of undersea mountain ranges (between 1000 and 3000 metres), as well as massive sulphides and the sulphide muds that form in areas of volcanic activity near the plate boundaries, at depths of 500 to 4000 metres.

Manganese Nodules

Covering huge areas of the deep sea with masses of up to 75 kilograms per square metre, manganese nodules are lumps of minerals ranging in size from a potato to a head of lettuce. They are composed mainly of manganese, iron, silicates and hydroxides, and they grow around a crystalline nucleus at a rate of only about one to 3 millimetres per million years. The chemical elements are precipitated from seawater or originate in the pore waters of the underlying sediments. The greatest densities of nodules occur off the west coast of Mexico, in the Peru Basin, and the Indian Ocean

Manganese nodules are composed primarily of manganese and iron. The elements of economic interest, including cobalt, copper and nickel, are present in lower concentrations and make up a total of around 3.0 per cent by weight. In addition there are traces of other significant elements such as platinum or tellurium that are important in industry for various high-tech products. The actual mining process does not present any major technological problems because the nodules can be collected fairly easily from the surface of the sea floor.

Cobalt Crusts

Cobalt crusts form at depths of 1000 to 3000 metres on the flanks of submarine volcanoes, and therefore usually occur in regions with high volcanic activity such as the territorial waters around the island states of the South Pacific. The crusts accumulate when manganese, iron and a wide array of trace metals dissolved in the water (cobalt, copper, nickel, and platinum) are deposited on the volcanic substrates. Their growth rates are comparable to those of manganese nodules. The cobalt crusts also contain relatively small amounts of the economically important resources. Literally tonnes of raw material have to be excavated in order to obtain significant amounts of the metals. However, the content of cobalt (up to 2 per cent) and platinum (up to 0.0001 per cent) is somewhat higher than in manganese nodules. Extracting cobalt from the ocean is of particular interest because it is found on land in only a few countries (Congo, Zaire, Russia, Australia and China), some of which are politically unstable.

Technologically, the mining of cobalt crusts is much more complex than manganese nodules. For one, it is critical that only the crust is removed, and not the underlying volcanic rocks. In addition, the slopes of the volcanoes are very ragged and steep, which makes the use of excavation equipment more difficult.

ASSIGNMENT

PETROLOGY

Q.1. (AMIE S13, 14, W14, 20 marks): Define process of formation of sedimentary rocks and basics of classification. Describe sedimentary rocks: (a) sand stone (b) limestone with type of economic mineral deposits hosted by them.

Q.2. (AMIE W16, 20 marks): Describe the formation and classification of igneous rocks. Give description of (a) granite (b) gabbro with example as host rock for metallic minerals.

Q.3. (AMIE W13, 7 marks): Define the term "metamorphism" as applied to rocks.

Q.4. (AMIE S16, 8 marks): Define metamorphic rocks and the process of formation.

Q.5. (AMIE S16, 12 marks): Describe common metamorphic rocks: (a) banded gneiss (b) mica schist (c) quartzite (d) marble.

Q.6. (AMIE W13, 7 marks): What are the agents of metamorphism and how do they play their roles?

Q.7. (AMIE W14, 8 marks): Differentiate between (a) Lignite and anthracite (b) marble and slate.

Q.8. (AMIE W15, 10 marks): Describe the origin of metamorphic rocks with details of footwall and hangwall of the gold and manganese ore bearing rocks in Indian geo-mining conditions.

STRATIGRAPHY/ MINERALOGY/ORE DEPOSITS

Q.9. (AMIE S14, 20 marks): Describe the role of (a) stratigraphy and (b) structures as control of localizing mineral deposits. Give suitable examples.

Q.10. (AMIE W13, 6 marks): Explain the term "metallogenic province."

Q.11. (AMIE W14, 8 marks): What are heavy minerals? name some of the heavy minerals.

Q.12. (AMIE S13, 20 marks): Describe in brief the origin, formation, mode of occurrence and distribution of major coal deposits in India.

Q.13. (AMIE W14, 20 marks): Describe the mode of formation of coal deposits. Where do the deposits of coal occur in India and when were they formed?

Q.14. (AMIE W15, 10 marks): Explain the process of formation of coal measure strata and distribution of coal deposits in India.

Q.15. (AMIE W13, 10 marks): Discuss various processes of ore formation.

Q.16. (AMIE W13, 7 marks): How is ore formation classified depending of the respective processes?

Q.17. (AMIE W15, 20 marks): Describe the mode of occurrence of sea-bed mineral deposit with neat sketches of formation of any two mineral deposits suitable for ocean mining.

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