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WINNING AND WORKING

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.

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.

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.

Extrusives

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

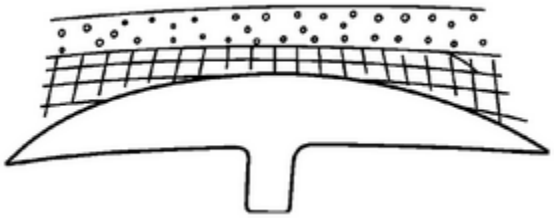
A volcano is considered as a conduit between the earth's surface and the body of magma, the crust beneath it. During volcanic eruption, lava is extruded from the volcanic vent and gases contained in the lava are ejected through it. Depending on the type of eruption, lava flows are divided into two groups: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

Intrusives (Minor)

Sills

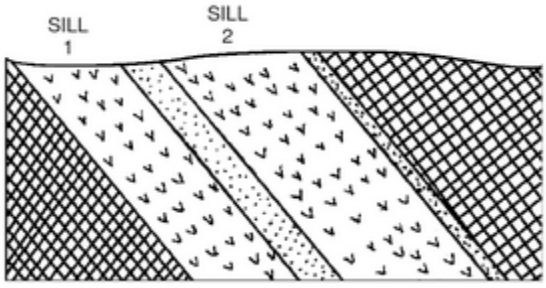
Sills are relatively thin tabular bodies of magma which essentially penetrate parallel to the bedding pianos of foliations of the country rocks. Sills are typically thin and shallow and are mainly located on unfolded country rocks. They are mostly basaltic in composition. A high

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

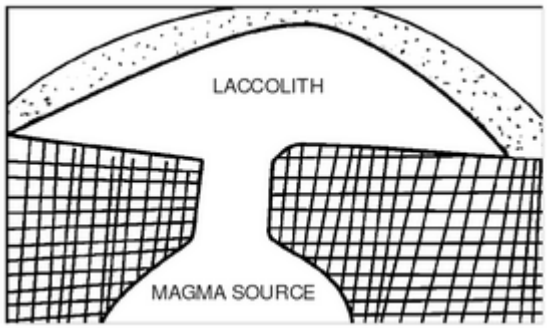
Multiple sills are formed as a result of more than one ejection.



Multiple sill

Laccoliths

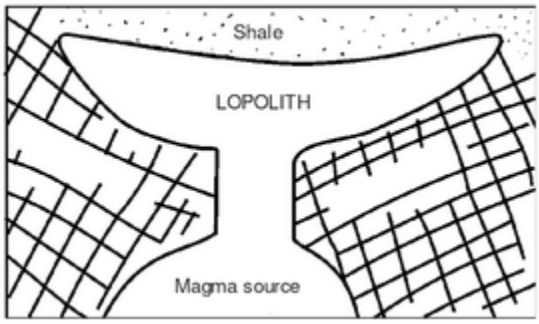
A laccolith is an intrusion with a flat floor and domed roof, the roof having been arched by the pressure from magma. High viscosity magma does not spread over but tends to form a bun shape (see figure).



Laccolith

Lopoliths

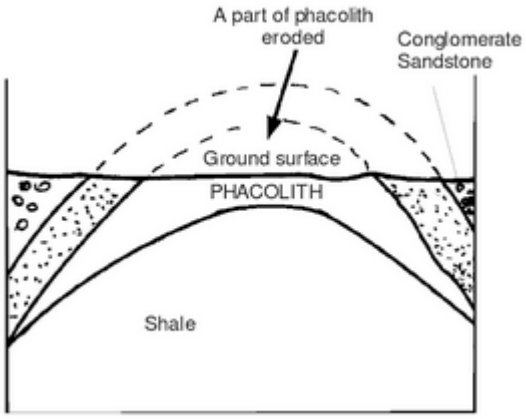
According to Grout's description, a lopolith consists of a large, lenticular, centrally sunken, concordant basin or tunnel -shaped intrusive mass (see figure).



Lopolith

Phacoliths

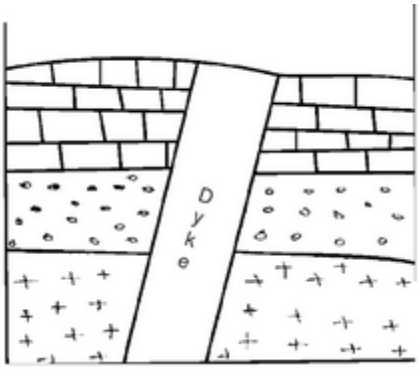
Phacoliths are intrusive concordant bodies mainly associated with folded rocks (see figure).



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.

- 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.

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.

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.

Basalt

Basalt is a simple mixture of labradorite, augite (essential) and iron oxides. It is similar to dolerite in mineral content. Vesicular and amygdaloidal structures are the most common in basalts.

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.

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.

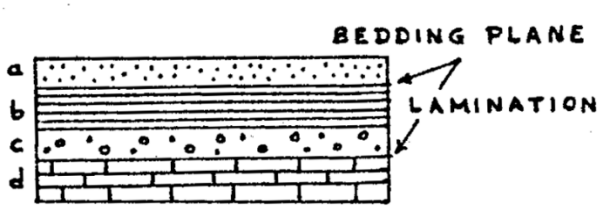
The branch of petrology which deals with the Study of sedimentary rocks and their equivalents is termed **sedimentary petrology**. Common sediments, such as sandstone, shale and limestone, form 95 per cent or more of all sediments.

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

Various terms are adopted by sedimentary petrologists.

Coarse	Gravel
Medium	Sand
Fine	Clay

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.

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.

Arenaceous Deposits

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

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.

Calcareous Deposits

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.

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.

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.

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

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.

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.

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.

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.

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.

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.

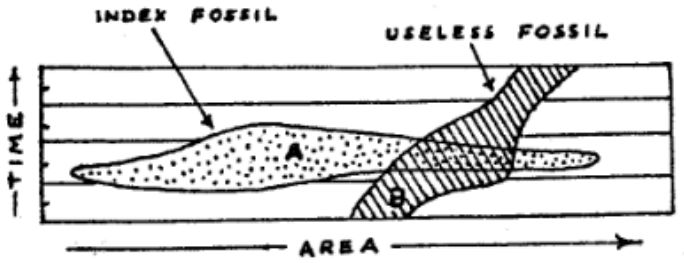
Mineral Composition. A marble is composed of grains of calcite or more rarely dolomite.

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".

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.

FOSSILS

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

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.

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.

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.

Sublimation Deposits

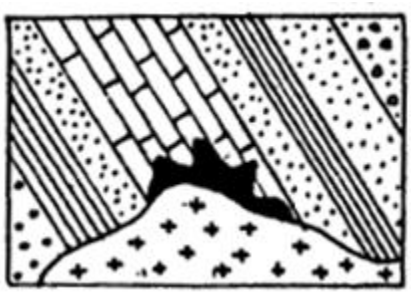
Sublimation is a very minor process of formation of ore deposits. Sublimation deposits contain only those minerals which have been volatilized by heat and subsequently redeposited in the same form at low temperature and pressure.

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.

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.

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.

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.

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

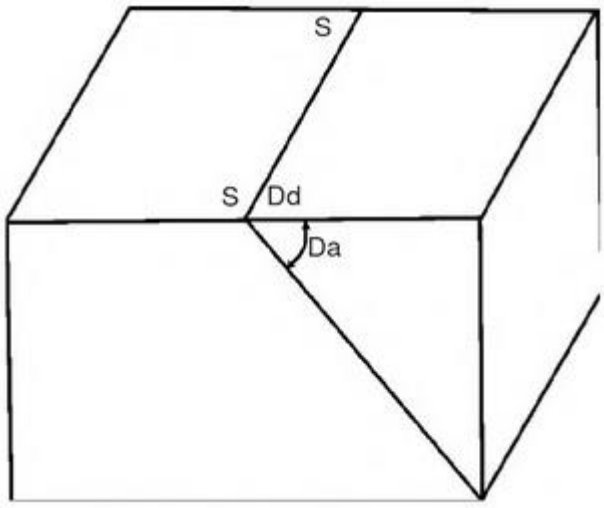
STRUCTURAL GEOLOGY

Strike

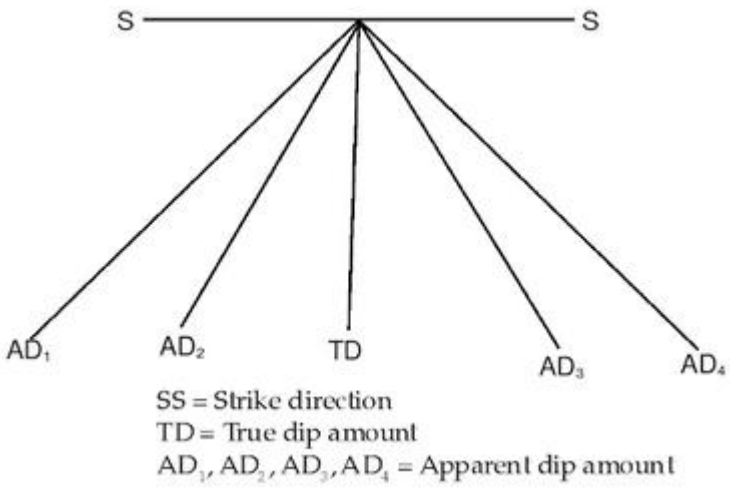
The strike of a bed is its general trend measured on a horizontal surface. In other words, strike is defined as the direction of a line formed by the intersection of the bedding and a horizontal plane.

Dip

The dip of an exposed bedding stratum is the angle between the bedding and a horizontal plane. The dip of a formation is measured in a vertical plane that is at right angles to the strike of the formation.



(a)



(b)

Strike and dip of a formation are shown in Figs. (a) and (b).

Folds

During geological processes, the rocks are subjected to stresses which result in undulations that are wavy. These wavy undulations are called folds. Fold size varies from a few centimetres to several kilometres.

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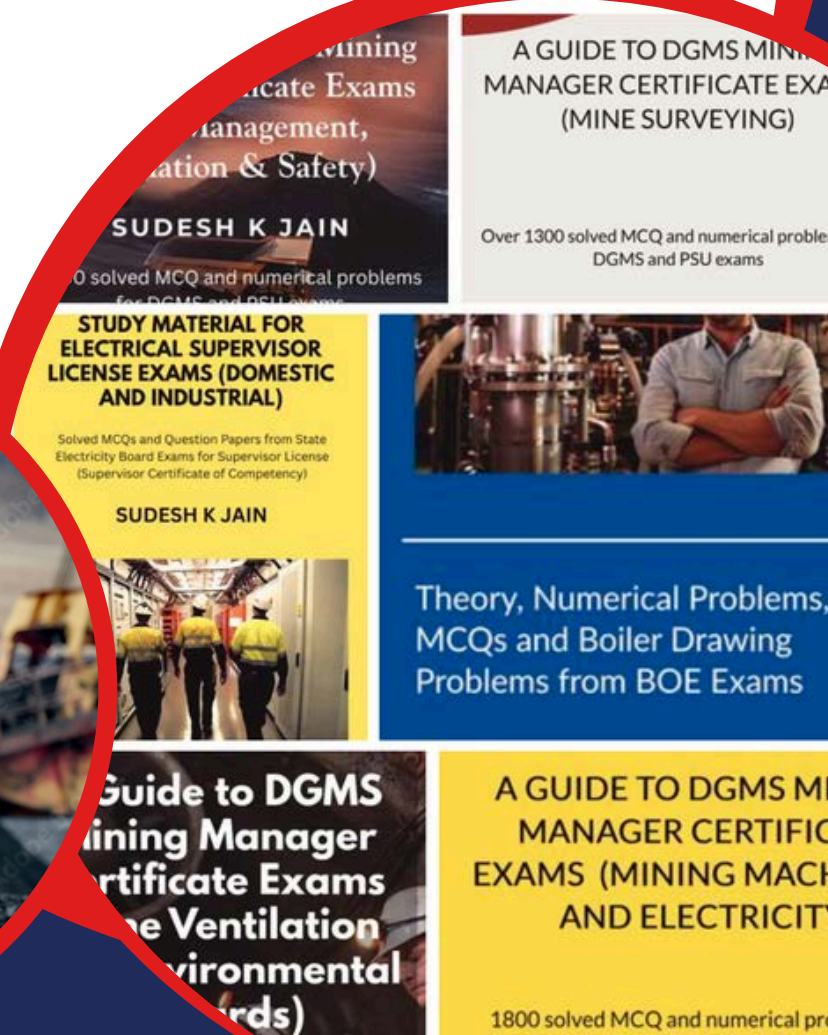


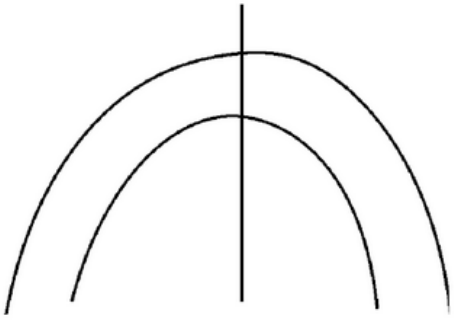
Parts of a Fold

Hinge

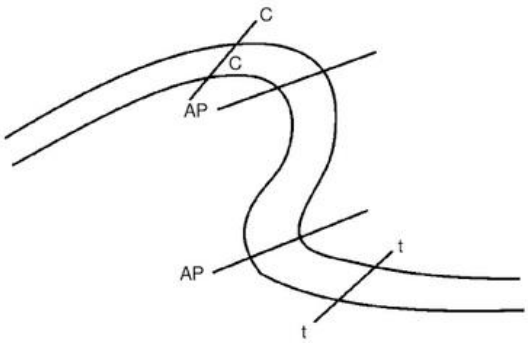
The hinge of a fold is the line of maximum curvature in a folded bed. There is a hinge for each folded bed. Hinges are characterised by their position and orientation.

Axial Plane

The axial plane is the surface connecting all the hinges. The axial plane may be a simple or a curved surface. However, the axial plane divides the fold into two equal halves as symmetrically as possible. Parts of a fold are shown in Figs. (a) and (b).



(a)



(b)

Axis

The axis is a line parallel to the hinge. It is the straight line moving parallel to itself that generates the fold.

Limbs and Flanks

Limbs are the sides of a fold. An individual fold consists of two limbs. A limb extends from the axial plane in one fold to the axial plane in the next. In a series of folds, every limb is mutually shared by two adjacent folds.

Plunge of the Fold

In most cases, the fold hinge is inclined in a horizontal direction and is called a plunge. The angle of inclination of the fold axis with the horizontal is measured as the plunge angle and direction.

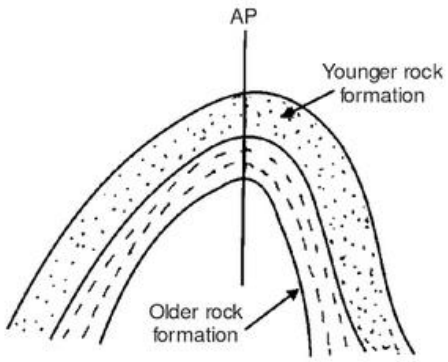
Crest and Trough

Folds show up-arched and down-arched bends. However, the line running through the lowest point is called a trough while the highest point is termed as a crest. The plane formed by all the crests is called the crest plane. The plane connecting the lowest parts of the same bed in an infinite number of cross-sectional lines is called the trough plane.

Classification of Folds

Anticline

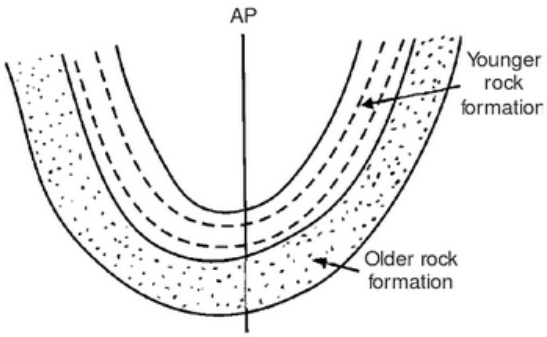
An anticline is defined as a fold in which the convexity is upwards. In this type of fold, older rocks are in the centre. The two limbs dip away from one another at the crest (see figure).



Anticline

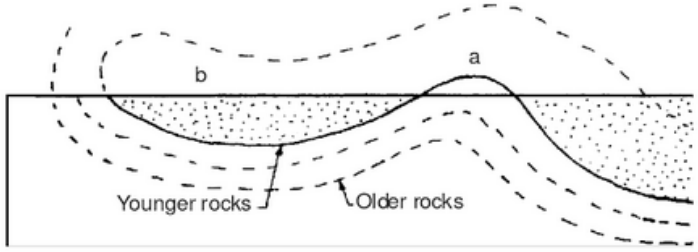
Syncline

A syncline is a fold in which the convexity is downwards. Syncline is a Greek word meaning inclined together. In this type of fold, younger rocks are in the centre of the limbs and the limbs of this fold dip towards each other at the trough (see following figure).



Syncline

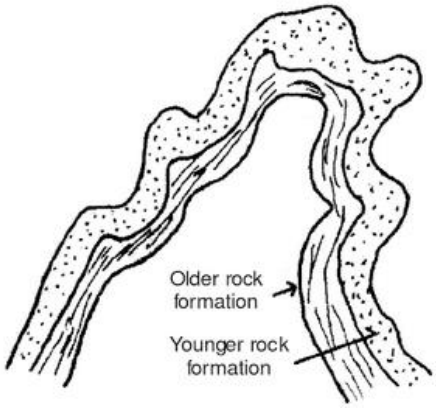
Antiform and synform are the terms used when stratigraphic successions in the field are not interpreted and only the shape of the fold is described (see following figure).



Antiform and synform

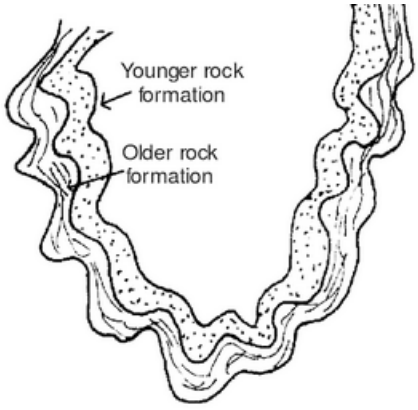
Anticlinorium

A major anticline composed of smaller folds is called Anticlinorium. See following figure.



Synclinorium

This is a large syncline fold comprising many smaller syncline folds (see following figure).



Geosyncline

The term Geosyncline means an earth syncline. However, this term is not used for the larger syncline. The term geosyneline is used for a large depression which is hundreds of kilometres

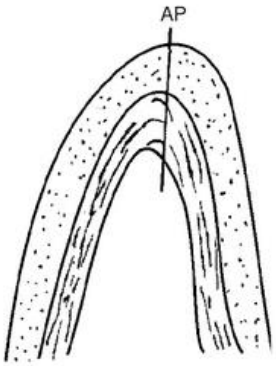
in length and tens of kilometres in width. Oceans are considered geosynclines. Sedimentary rocks are formed from geosynclines.

Geanticline

A geanticline is like a geosyncline in size but lies outside or inside it.

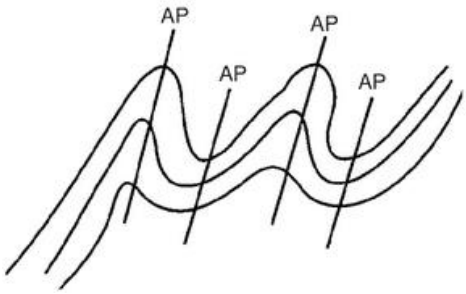
Symmetrical Fold

A symmetrical fold is one in which the axial surface is vertical (see following figure).



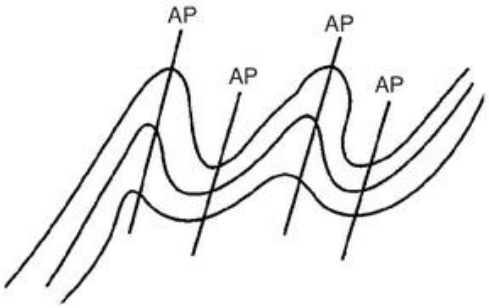
Asymmetrical Fold

An asymmetrical fold is one in which the axial surface is inclined (see following figure).



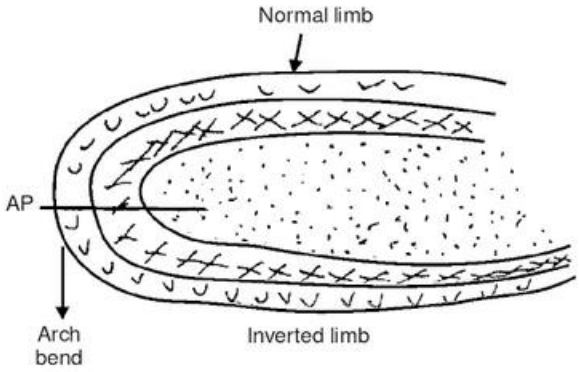
Overturned Fold

An overturned fold is one in which the axial plane is inclined and both limbs of the fold dip in the same direction, with varying dip angles (see following figure).



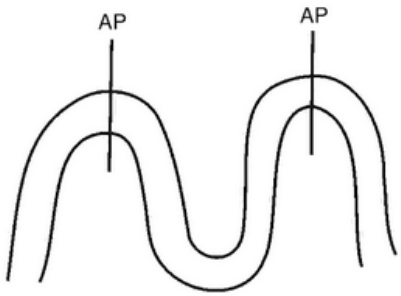
Recumbent Fold

A recumbent fold is one in which the axial plane is essentially horizontal. Rock strata in the inverted limb are generally thinner than the corresponding beds in the normal limb (see following figure).

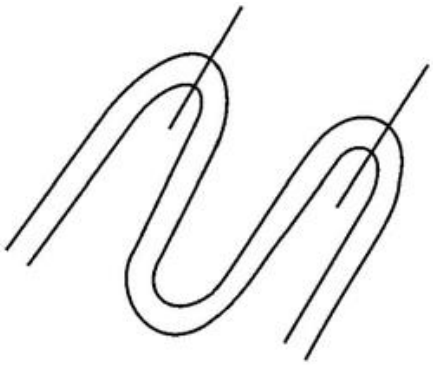


Isoclinal Fold

An isoclinal fold means equally inclined, wherein, the two limbs of the fold dip at equal angles in the same direction (Figs. a and b).



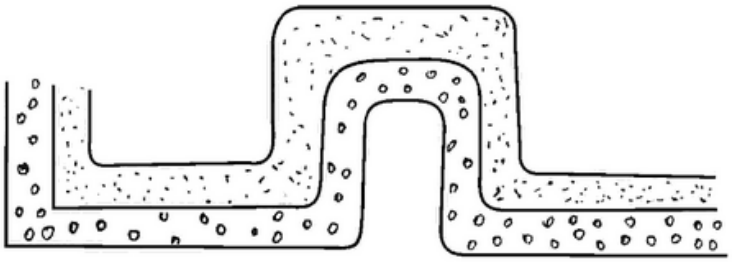
(a)



(b)

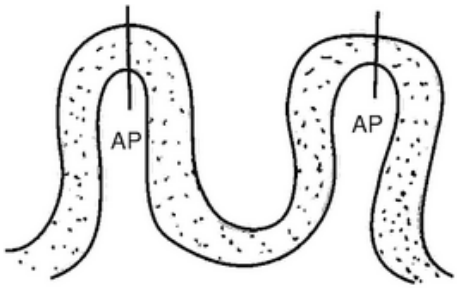
Box Fold

A box fold is one in which the crest is flat and broad. However, two hinges are present, one lying on either side of the flat crest.



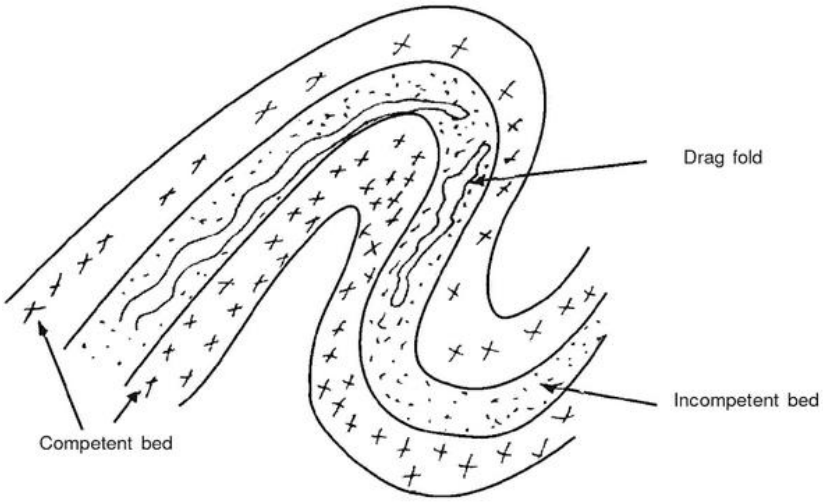
Fan Fold

A fan fold is one in which both limbs of the folds are overturned.



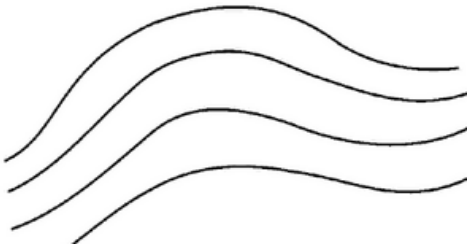
Drag Fold

Drag folds develop when a hard bed slides past a weak or incompetent bed. Such a situation favours the formation of asymmetric folds termed as drag folds. However, the axial plane of the drag fold is inclined at an angle to the competent bed strata.



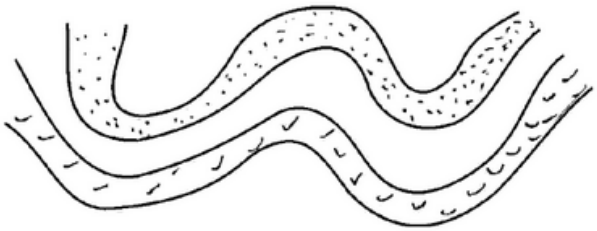
Open Fold

In an open fold, the rock constituents of a bed do not move, in other words no flowage occurs. Hence, beds are more or less uniform in thickness.



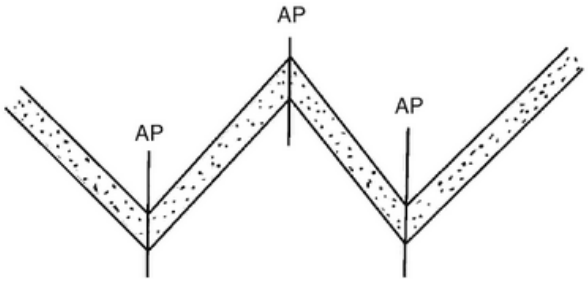
Closed Fold

In a closed or tight fold, the rock constituents come out from the limbs of the fold and gradually thicken at crests and troughs.



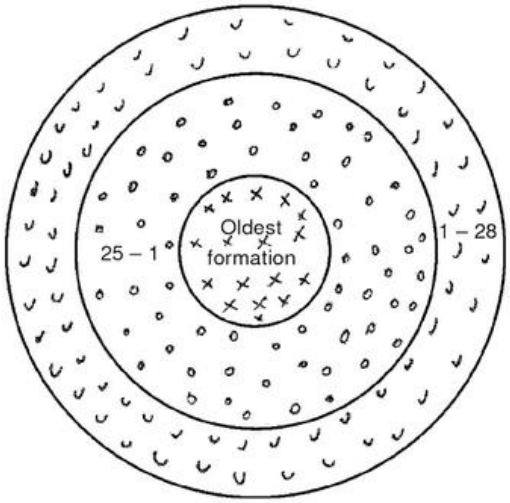
Chevron Fold

A chevron fold is defined as a fold in which the hinges are sharp and angular.



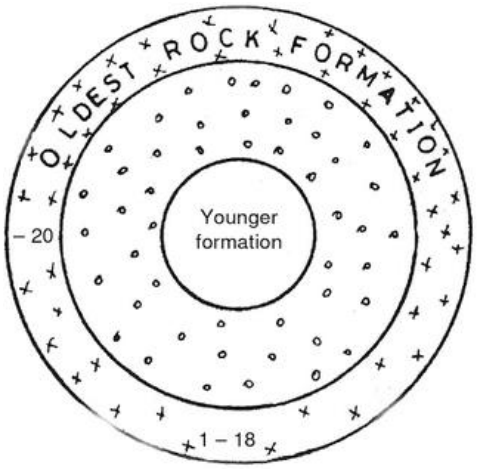
Dome

A dome is described as an anticlinal uplift that has no distinct trend.



Basin

A basin is described as a synclinal depression that has no distinct trend.



Causes of Folding

Folds are formed mainly due to

- a tectonic process
- a non-tectonic process.

Folds resulting from a tectonic process are formed mainly due to the forces within the crustal layers of the earth. Folds resulting from a non-tectonic process are formed mainly due to the geological process operating on the exposed lithological formation, resulting in erosion, transportation and deposition of sediments.

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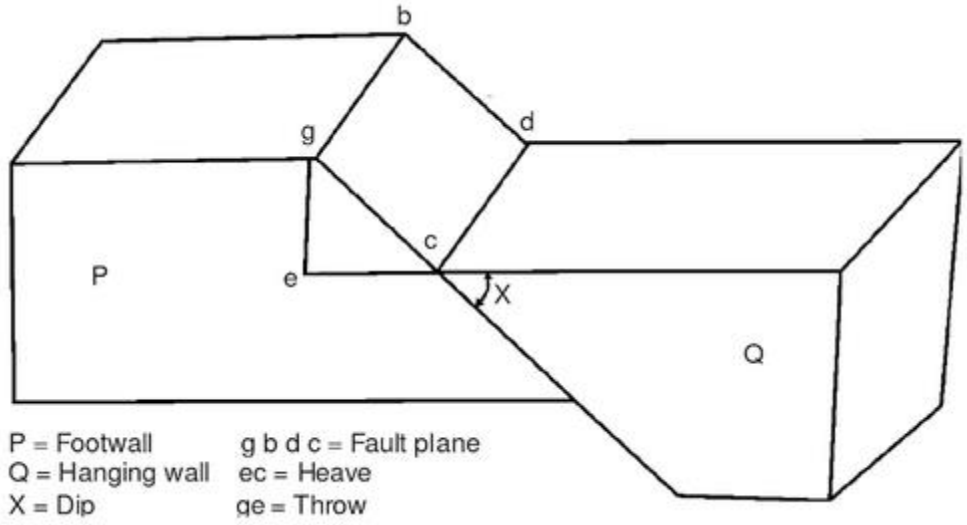
Faults

Faults are described as natural ruptures along which the opposite walls have moved with respect to each other. Fractures are the result of stresses and shearing; the rocks gradually generate fractures along the direction of these forces. Faulting results due to fracturing in which the rock blocks move up and down towards each other. Some faults are considered micro faults, whose length can be measured in a few centimetres or a few millimetres. However, major faults vary in size from a few kilometres to thousands of kilometres in length. A recent plate tectonic study revealed that intercontinental faults run along the major stress zones of the world.

Parts of a Fault

The different parts of fault have been shown in following figure.



Fault Plane

The surface along which the fracture occurs in the rock mass and along which the movement of rock blocks take place is called a fault plane.

Hanging wall

In an inclined fault plane the upper surface of the fault plane is called the hanging wall.

Footwall

In an inclined fault plane the lower surface of the fault is known as the footwall.

Strike

The strike of a fault refers to the trend of the horizontal line in the plane of the fault.

Dip and Hade

The dip of a fault is the angle between the horizontal surface and the plane of the fault, whereas, hade is defined as the angle between the fault plane and the vertical plane that strikes parallel to the fault.

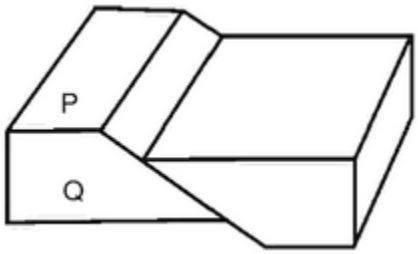
Slip

The term slip is used for measuring relative displacement of formerly adjacent points on opposite sides of the fault and is measured in the fault surface.

Classification of Faults

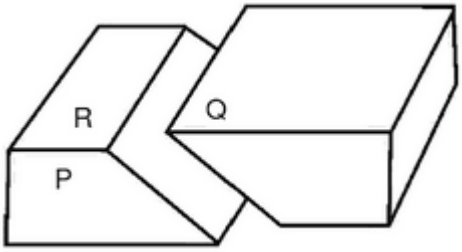
Net slip

Net slip is the total displacement of the fault surface between two formerly adjacent points located on opposite walls of the fault (see figure).



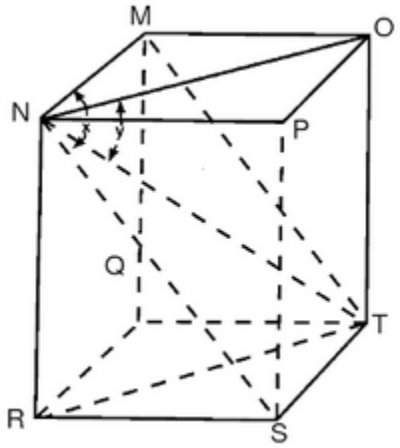
Dip slip

The dip slip is the component of the net slip measured parallel to the dip of the fault plane (see figure).



Rake

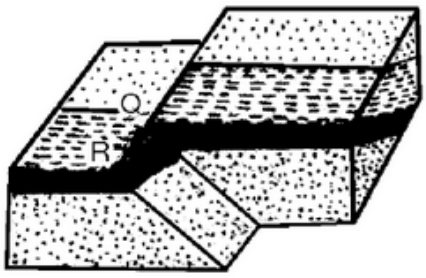
This is defined as the angle which a line in a plane forms with the horizontal line in that plane (see figure).



Rake, throw and heave plunge

Classification of faults based on the rake of the net slips

Dip-slip fault: A dip-slip fault is one in which the net slip is below or above the dip of the fault plane.



Dip-slip fault: A dip-slip fault is one in which the net slip is below or above the dip of the fault plane.

Diagonal-slip fault: One in which the net slip runs diagonally up or down the fault plane.

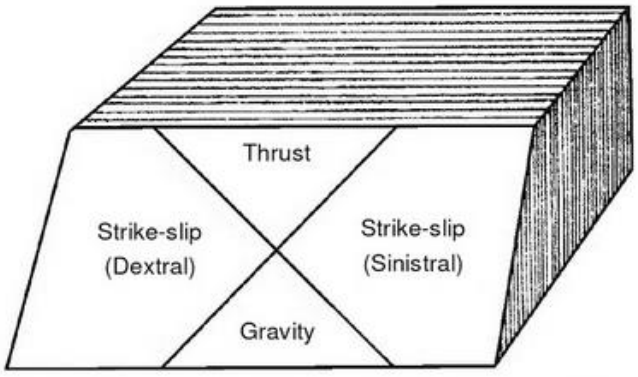
Bedding fault: One in which the strike of the fault is parallel to the bedding.

Longitudinal fault: One in which the strike of the fault is parallel to the strike of the regional rock structure.

Transverse fault: One in which the strike of the fault is diagonal or perpendicular to the strike of the regional rock structure.

Genetic Classification of Faults

Normal fault: One in which the hanging wall has moved downwards relative to the footwall. This type of fault is also known as a gravity fault (see figure).



Reverse fault: One in which the hanging wall has apparently moved upwards relative to the footwall. The angle of inclination to the horizontal of a reverse fault plane is less than 45° (see above figure). Such faults are also known as thrust faults.

Strike-slip faults: Faults in which the displacement is parallel to the strike of the fault (see above figure).

PROSPECTING

"Prospecting" is the systematic process of searching promising mineral targets identified during Reconnaissance. The objective is more definitive exploration for increasing geological confidence leading to further exploration.

The prospecting methods are broadly classified into two groups:

- airborne prospecting methods, and
- ground prospecting methods.

Airborne Prospecting Methods

The airborne prospecting methods include "remote sensing methods" in which photo geological study is undertaken, and "aerial geophysical prospecting methods". By these methods large areas are covered quickly and target areas are outlined for ground prospecting.

Ground Prospecting Methods

The ground prospecting methods are broadly classified into two groups:

- surface methods, and
- geophysical methods

In *surface prospecting methods* data are obtained by direct observation. Most of the information comes from natural exposures and artificial openings such as pitting, trenching, drilling, etc.

In the *geophysical methods*, the information is obtained indirectly by studying the physical properties of rocks.

Surface Prospecting Methods

- Geological mapping.
- Test pitting, trenching, and aditting.
- Auguring and wash boring.
- Drilling.

Geophysical methods

- Gravity methods
- Magnetic methods
- Electrical methods
- Seismic methods.

Geological Mapping

Before starting the prospecting work, a target area that can yield mineral deposits, is selected. Then its geological map is prepared on a suitable scale. Such a map shows topography, rock outcrops, and structural features such as dip, strike, folds, faults, etc. This sort of map gives an idea of the length and width of the deposit. It also serves as a base map for planning out a trenching, pitting or drilling programme.

Trenching

A "trench" is a narrow linear excavation which is made to expose ore bodies concealed under soil cover. The trenches may be 6 to 9 meter long, 1 to 1.5 meter wide, and 2 to 2.5 meter deep. They are commonly dug across the strike of the ore body at intervals of 15 to 150 meters. The spacing of trenches depends upon the consistency of data. Prospecting by trenching is generally done when the ore outcrops are narrow and the soil cover is thin (about one meter). The trenching gives reliable information about the geology, structure, extension and grade variation of the ore body. This method has been adopted as a major prospecting method in may iron ore and bauxite deposits.

Pitting

The process of digging rectangular openings to penetrate soil cover to reach ore bodies concealed underneath is called "pitting". The common dimension of pits is 1.2 m x 1.2 m x 6 m. However pits may be sunk to a depth of about 10 meters beyond which they become very expensive. Pitting is a very useful method of prospecting those ore bodies which are flat or gently dipping and lying near the ground surface. For steeply dipping ore bodies and those

having linear and narrow outcrops, pitting would not be favourable. The pattern of the layout of the pits may be regular or irregular. In a regular system pits are sunk in rows in grid or triangular pattern. Pitting is an important method of prospecting in many bauxite and iron ore deposits.

Aditting

The "*adits*" are horizontal openings which are dug in mountainous terrain to explore ore bodies. An adit many be driven across or along the strike of rocks. It should be dug in such a way so that at a later stage it could be used as an opening for exploiting the ore.

Auguring and Washboring

Auguring and washboring are commonly used for prospecting of flat and homogeneous deposits like clays which are concealed under a thin cover of soft and unconsolidated materials. "**Auguring** " is a simple method of putting down holes of about 2.5 cm in diameter to depths upto 6 meters in soft soils. An auger consists of a screw blade mounted on a steel pipe. It is screwed into the ground by turning on a T-pipe attached to the upper end.

In "**washboring**" a hole is dug in the soft ground by forcing a jet of water through the wash-pipe. The soil thus eroded comes to the surface a$ a suspension in water where it is examined and identified.

Drilling

Drilling is an important method of prospecting subsurface rocks and ore deposits. In drilling data are collected by direct penetration of subsurface rocks by drill holes. The samples of rocks are obtained in the form of cylindrical cores or rock fragments. The drill holes provide the following informations.

- Size, shape and morphology of the ore body.
- Geological structures and number of lodes present.
- Nature of the host rocks.
- Composition and grade of the ore body.

GEOLOGICAL MAPS

A geological map shows the geological set-up of an area in terms of occurrence and distribution of various rock types. In addition to outcrops, such a map also reveals the altitudes and structure of rocks, and their association with topography and drainage. Geological maps, therefore, provide the key for understanding the structure and geological history of any particular region. These maps have a wide range of application in mineral prospecting, mining and civil engineering works.

Topographical Maps

A topographic map is one which shows the configuration of the land surface and drainage details of the area. It also shows man made features such as roads, railways, villages, towns, etc. Contour lines are commonly used to depict elevations on the topographic maps.

Outcrop

The exposure of rock beds on the ground surface is called "*outcrop*". Geological maps show a variety of outcrop patterns. Outcrop pattern of strata is determined by two factors : (i) dip and strike of strata, and (ii) the topography of the area.

BLASTING

The blasting operations must be carried out to provide quantity and quality requirements of production in such a way that overall profits of mining or quarrying operation are maximised. In-situ rock is reduced in size by blasting and crushing into the required size or with additional grinding, into a finer powder suitable for mineral processing.

Fragmentation

Primary fragmentation occurs during the detonation phase. The shock waves exceed the compressive and the tensile strength capacity of the rock, and the rock is crushed and pulverized close to the drill hole, and radial cracks will be created out from the hole to a certain extent (equal to 4 – 5 times the hole radius). The gas pressure will penetrate new cracks and existing fissures and joints, loosening the rock mass and throwing it out and over the bench floor.

Secondary fragmentation breakage starts with the throw when fragmented material accelerates out from the bench.

Controllable factors which influence primary fragmentation:

- Drill hole diameter
- Mass of explosive charge
- Stress waves' peak values
- Charge distribution in the bench

EXPLOSIVES & ITS CLASSIFICATION

Explosive is a solid or liquid substance or a mixture of substances which on application of a suitable stimulus is converted in a very short time interval into other more stable substances, largely or entirely gaseous, with the development of heat and high pressure.

Classification of Explosives

The explosives can be classified into the following types:

- Low (or deflagrating) explosives
- High explosives (a) Primary and (b) Secondary.

Low explosives were the earliest to be developed. These lead to an explosion which is really a rapid form of combustion in which the particles burn at their surfaces and expose more and more of the bulk until all has been consumed. Such an explosion is called deflagration and the reaction in this case moves slower than the speed of sound. Typical examples of this category are the blasting powder or gun powder, propellants in ammunition, rocket propellants and pyrotechnics.

High explosives, depending on their composition, explode at velocities of 1500-8000 m/s and produce large volumes of gases at considerable heat at extremely high pressures. High explosives themselves may be further subdivided into **primary explosives** and **secondary explosives.**

Primary explosives are characterised by their sensitiveness to stimuli like weak mechanical shock, spark or flame, the application of which will take explosive compounds from state of deflagration to detonation easily. Examples of these explosives are Mercury Fulminate, Lead Azide and other mixtures. These explosives are used as initiating charges in the initiating devices such as detonators.

Secondary explosives are capable of detonation only under the influence of a shock-wave, normally generated by the detonation of primary explosives. Secondary explosives of this type are military explosives like TNT, RDX, PETN, Tetryl and other combinations of these and industrial explosives like nitro-glycerine, emulsion, slurries, watergels, ANFO and other powder explosives. These explosives are normally set off with suitable initiating devices like detonators or detonating cords and in some cases there is need of initiation by another high explosive. The explosive needing another high explosive is called **Blasting Agent** such as **ANFO**, some slurries, some emulsions and mixtures of emulsions and ANFO.

Nitro-glycerine (N.G.)

It is an oily fluid with sp. gr. of 1.6 and freezing point at 13°C. It is insoluble in water and is very sensitive to explosion by shock of any nature. The sensitivity to shock increases when nitroglycerine freezes. "lb render it suitable for industrial use, it must either be absorbed by some inert material or be gelatinised. NG based explosives are available in 3 consistencies; gelatinous, semi gelatinous and powdery. All explosives containing NG have a highly shattering effect and they produce fumes which cause headache after long exposure. Explosives containing NG are liable to freeze when the temperature falls to 8° or less and are then more

sensitive to detonation by friction and impact. To avoid this, a low freezing agent, usually di-nitro-glycol which is itself as powerful an explosive as NG, is used. Low freezing explosives are designated by such prefix as "Polar", e.g. Polar Viking. Polar special gelatine, etc.

Ammonium Nitrate (NH_4NO_3)

It is a white hygroscopic salt, very soluble in water and is comparatively very safe to handle. When it is detonated it is, however, a powerful explosive. Though ammonium nitrate is more powerful than the low explosives it is not as powerful as N.G. and it is difficult to denote it by itself with the help of a detonator, but it can be detonated by a booster of high explosive.

To use ammonium nitrate as an explosive, it should be mixed with diesel oil, N.G. or TNT. Ammonium nitrate is an interesting compound, . In that it is a high explosive, an oxidising agent, and a cooling agent at one and the same time. Prilled (a pellet or solid globule) ammonium nitrate of fertiliser grade mixed with diesel oil is used for large dia. holes in quarries.

Ammonium nitrate does not occur in nature and it is prepared by reacting ammonia gas with nitric acid. When detonated by extreme shock NH4N03 decomposes according to the equation.

$$2NH_4NO_3 = 4H_2O + O_2 + 2N_2 + 346 \text{ kcal/gm}$$

This property comes into play in the utilisation of NH_4NO_3 as an explosive.

Ammonium Nitrate Dry Mixes (ANFO)

Prilled (a pellet or solid globule) ammonium nitrate (AN) and fuel oil (FO) mixtures, known as ANFO, were introduced for blasting operations in mid 1950s. Ammonium nitrate in a proper form when mixed with carbonaceous or combustible material in appropriate proportion forms a blasting agent. Although, many forms of AN could be used with a solid or liquid fuel to form a blasting agent, the porous prilled forms are preferred for ANFO. Through the years, fuel oil has proved itself to be an almost ideal fuel for AN.

It is readily available, is inexpensive and easily mixed with AN to produce a uniform mix commonly known as ANFO. Small porous spherical prills absorb oil readily giving a dry mix which has good pouring properties. The microprills in each prill allow the AN to absorb and retain the optimum amount of fuel oil. The prills are hard enough to withstand transport shocks without breaking down, yet soft enough to breakdown and give a high loading density when blow loaded into blast holes with equipment such as pneumatic blast hole charger.

AN is stable at ambient temperatures but can absorb moisture from the atmosphere if the humidity is above about 60%. To minimise moisture absorption and caking, the prills are lightly coated with anti-caking agents. While it is strong supporter of combustion, AN is not flammable. However it is an oxidiser.

Proper mixing of AN and FO is important for predictable explosive performance.

The most common method of mixing small quantities of ANFO is to pour the correct amounts of both ingredients into a hand-operated mixer (concrete type) and after thorough mixing, tip the ANFO back into the empty bags, and from there into blastholes. Such mixing care is essential for small diameter blastholes and for maximum explosive energy output. Commonly, the bowl is lined with plastic or epoxy resin to prevent corrosion. Aluminium bowl is also used.

Where several users require relatively large amounts of ANFO, a central mixing plant is sometimes installed to meet this need. Mixing of AN and FO constitutes manufacture of an explosive. For this reason, a license or permit to mix ANFO must be obtained from the statutory authority.

Although ANFO mixtures are explosives, they are relatively insensitive and unless suitably primed, reliable detonation in large blastholes will not occur. The size and type of primer required depends upon blasthole diameter, degree of confinement, dryness of blastholes, etc. In general, the primer should have a high VOD and the maximum possible diameter. Needless to mention, the primer should be in intimate contact with the ANFO.

Lack of water resistance is the major limitation and disadvantage of ANFO. AN is readily dissolved by water, and, unfortunately the addition of 5.64% FO does little to reduce the rate of dissolution. Both die strength and VOD of ANFO are reduced by the addition of water. ANFO which contains more than about 10% water usually fails to detonate. As one would expect, the longer ANFO is exposed to water, the greater is the damage, and the lower the blast effect. Wherever there is a chance of blasthole water desensitising ANFO and make it less effective, efforts should be made to minimise the period between charging and firing the blast.

The experience of thousands of the mine operators throughout the world provide ample warning that the blasting performance of the ANFO cannot be relied upon in the presence of water in blasthole. The efficient use of ANFO in wet blasthole depends almost entirely upon the protection given to it by polyethylene liners or by the packaging materials used to make up cartridges of ANFO. Dewatering of blastholes is also carried out. The use of Heavy ANFO has allowed operators to overcome this important shortcoming.

Slurry Explosives

Slurry explosives were first developed as a result of attempts to waterproof, improve density and strength of ammonium nitrate.

A slurry is a mixture of nitrates such as ammonium nitrate and sodium nitrate, a fuel sensitiser, either explosive or non-explosive, and varying amounts of water. Although they contain large amounts of ammonium nitrate, slurries are made water resistant through the use of gums, waxes, and cross linking agents.

Emulsion Explosives

An emulsion is a two phased system in which an inner or dispersed phase is distributed in an outer or continuous phase. In simpler terms an emulsion is a mixture of two liquids that do not dissolve in one another. This unique feature coupled with the fact that minute size of the nitrate solution droplets are tightly compacted within the continuous fuel phase results in good intimacy between the oxidiser and fuel and increased reaction efficiency compared to other systems.

Three products are available in emulsion category. These products are as given below:

- Straight emulsions;
- Doped emulsions;
- Repumpables

Straight emulsions

Basic formulation of an emulsion explosive can be represented as follows:

Ingredient	Weight (%)
Ammonium nitrate	60 - 70
Calcium nitrate/Sodium nitrate	0 - 20
Fuel oil	2 - 6
Aluminium	1 - 3
TNT & Water	Varies

Straight emulsions are normally hot mixed at temperature over 50°C and a suitable chemical gassing agent is incorporated to control density. Since the final product is straight emulsion, the explosive displays exceptionally high water resistance, stability and explosive reaction efficiency leading to superior velocity of detonation (VOD) characteristics.

Doped emulsions

This is a generic term for emulsion explosive to which varying percentage of ammonium nitrate are added to achieve a wide range of strengths. Pumpable characteristics as in the case of emulsions are maintained at all stages and so also the superior VOD and water resistance properties of emulsions.

Repumpable emulsions

These formulations are designed for small and intermediate diameter and apart from the normal advantages of emulsions are designed for pumpability at low temperatures.

These are low cost units for fast and accurate loading of small quantities per borehole. Like all bulk explosive all the components are non-explosive and are mixed on the mine bench and loaded directly into the borehole.

Heavy ANFO

None of the above slurry and emulsion systems have cost competitiveness with ANFO as such their usage has been limited. The exception to this is densified or Heavy ANFO. The aim in Heavy ANFO is to have the advantages of both, the high density and water resistance of slurries and emulsions plus the low cost of ANFO. In the mix of Ammonium Nitrate and Fuel Oil about 50% of air in total volume exists, roughly 30% in the prills and 70% between the prills. This volume is filled with a high density, waterproof product such as emulsion (15-40%), the resultant mix is denser and more water resistant than ANFO and with very little added cost.

EXPLOSIVE PROPERTIES

Each explosive has certain specific characteristics or properties. Some of the principal properties of explosives which influence the ultimate choice are:

Detonation velocity; strength energy; detonation pressure; density; safety in handling; storage qualities; water resistance; sensitivity; sensitiveness; medical aspects; inflammability; resistance to freezing; permissibility.

Detonation Velocity

The detonation velocity is a measure, in meters per second or feet-per-second, of the speed at which the detonation wave travels through a column of explosives. Many factors affect the detonation velocity such as explosive type, diameter, confinement, temperature, and priming.

- **Type** The detonation velocities of today's commercial explosives range from about 1500 m/s e.g. ANFO in small diameter holes and certain permissibles to more than 6700 m/s e.g. detonating cords and cast-primers. Every explosive has an ultimate or ideal velocity known as hydrodynamic velocity, which is the steady-state velocity of the explosive. As a general rule, the higher the velocity the greater the shattering effect; thus when harder rock is to be blasted, a higher velocity explosive should be chosen. It is to be noted that velocity is not the solitary property which influences the power of an explosive.
- **Diameter** Depending upon the type of explosive up to a certain diameter the velocity of detonation of an explosive is influenced by the diameter. In general, the larger the diameter the higher the velocity until the steady state velocity of the explosive is reached. Every explosive also has a **'critical diameter'** which is the minimum diameter at which the detonation process, once initiated, will support itself in the column

- **Degree of confinement** Generally, the greater the confinement of an explosive, the higher the detonation velocity. This is particularly true for products such as ANFO and some watergels in small diameter boreholes. Depending on the type, the degree of confinement has less effect on the velocity as the diameter of the explosive increases. If the diameter is small enough, the detonation may ultimately decay and fail. With the increase in the diameter of the explosive, however, the degree of confinement gets less and less effective.
- **Temperature** Depending on the type of explosive, changes in its temperature affect the velocity of the detonation. A decrease in temperature will decrease the sensitivity of any explosive.
- **Priming** It is essential that adequate priming is ensured so that the explosive may reach its maximum velocity as quickly as possible. Inadequate priming can result in the failure of the explosive to detonate, a slow build-up to final velocity, or a low velocity detonation.

Explosive energy

The performance of an explosive is not determined simply by knowing the total energy released by the explosive. It depends also upon the rate of energy release and how effectively the energy is utilised in fragmenting and moving the material being blasted. Both the explosive properties and the properties of the material being blasted influence the effectiveness of an explosive. Some of the current tests or calculations to measure and characterise an explosive energy are the various underwater tests, the pressure time measuring technique in the rock, and the theoretical calculation techniques.

Density

The density of explosives is expressed in g/cm^3. In general commercial watergels. emulsions and nitro-glycerine based explosives commonly used are in the range of 1.10 to 1.35 g/cm^3.

Critical Density An explosive sensitivity can be reduced or destroyed by too much increase in density. If the density becomes too high and the 'critical density' is exceeded then even a good primer may not detonate the blasting material.

Detonation Pressure and Explosion Pressure

The detonation pressure, usually measured in kilobars, is generally considered as the pressure in the shock zone ahead of the reaction zone. When an explosive detonates, this tremendous pressure is released, practically instantaneously, in a shock wave which exists for only a fraction of second at any given place. The sudden pressure thus created will shatter rather than displace objects and is generally accepted as providing to an explosive an ability called **brisance**. This brisance or shattering effect is dependent upon the suddenness with which the

gaseous products of an explosive are liberated. The detonation pressure is a function of the density, the detonation velocity, and the particle velocity of the explosive.

The detonation pressure is different from the **explosion pressure**, which is the pressure after adiabatic expansion back to the original explosive volume. The explosion pressure is theoretically about 45% of the detonation pressure. The effective explosion pressure in blasting depends on how well the explosive fills the holes.

Water Resistance

The ability of an explosive to withstand water penetration, termed as water resistance, vary widely for the various explosives. In many blasting situations explosives have to remain under water for long periods of time. Even in case of common rock blasting operations the drill holes are full of water. Water resistance is generally expressed as the number of hours a product may be submerged in static water and still be detonated reliably.

Sensitiveness

Sensitiveness of an explosive is a measure of its propagating ability. For NG-based explosives and some slurries it is the distance in inches or centimetres over which one half of 25 mm x 200 mm cartridge would propagate to another one-half of a 25 mm x 200 mm cartridge when both halves with the cut-ends facing were enclosed in a paper tube and shot unconfined. This is termed as **'gap sensitivity'.**

SAFETY IN HANDLING EXPLOSIVES

Safety in handling is very important and one obvious requirement of an explosive is that it can be transported, stored and used under normal conditions without any risk to people carrying out blasting operation. Explosives are subjected to many tests before they are approve.

- **Drop hammer test.** In a standard test for dynamite a specified weight is dropped from varying heights until a drop distance is reached at which the product, usually a thin section on a metal plate detonated 50% of time. With many slurry and emulsion explosives and ANFO such method do not show any detonation within standard test limits.
- **Friction tests.** In this test friction under increased pressure is applied upon a small amount of explosive. When a reaction in the explosive is obtained the pressure is noted.
- **Riffle bullet test.** A determination is made of the bullet velocity needed in order to create a detonation of the explosive.
- **Heat test.** A determination is made of how much heat an explosive can withstand before a reaction starts and what happens when an explosive starts to decompose with heat.

DETONATORS

High explosives are initiated by detonators or detonating fuses. A detonator is a small copper or aluminium tube containing essentially a small auxiliary charge of special explosive. A chemical reaction initiated by a flame or electric current in the special explosive can build up very rapidly into an explosion of sufficient intensity to project a detonation wave throughout a high explosion enclosing the detonator.

Detonators are of the following types :

Plain detonators

These are fired by safety fuses, the spark or "spit" from the fuse causing the detonator to explode; these are sometimes called "ordinary" detonators.

Ordinary electric detonators

These are fired by passage of electric current through the detonator. They are further subdivided as : (a) Low tension detonators, and (b) High tension detonators (not generally used in mining).

Ordinary electric detonators are of instantaneous type, i.e. without any delay element. They are of copper or aluminium tubes.

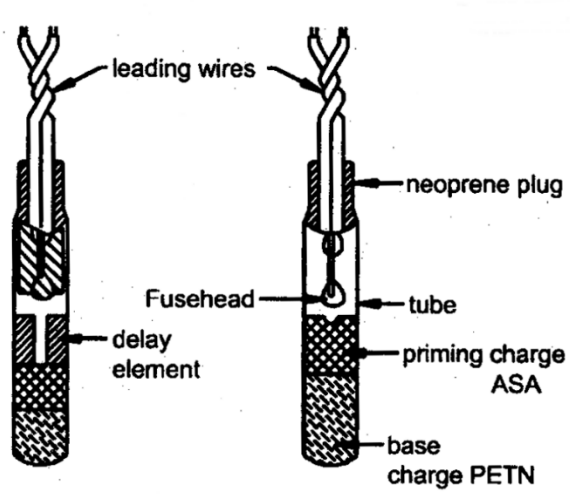
Delay detonators

These are essentially low tension electric detonators with a delay element, the object in their use being to phase the firing of shots, so that time and effort are saved in charging and firing several successive rounds of shots.

These are subdivided as :

- Half second or long delay detonators, and
- Milli-second delay detonators (also known as short delay detonators).

In appearance and composition, this is like the L.T. detonator. [The L.T. detonator described above is of instantaneous type; the moment voltage is applied to it, the detonator explodes and along with it, the (enclosing explosive. A delay detonator has a delay element introduced between the fuse head and the priming charge. (see figure).



(a) Section of delay detonator **(b) Ordinary electric detonator**

The delay element consists of a copper or brass sleeve filled with a special composition which bums at a specified rate and the delay is obtained by varying the length of the sleeve containing the special composition.

Permission from the D.G.M.S. is required before using delay detonators in underground coal mines. Delay detonators and non delay detonators should not be kept in the same box.

Safety Fuse

A safety fuse which looks like a cord consists of a core of fine grained gunpowder wrapped with layers of a tape or textile yarn and waterproof coatings. The burning speed is usually 100 to 120 sec/ metre. When one end of the fuse is ignited, it carries the flame at a uniform rate to ignite gun powder or to detonate an ordinary detonator which is turn can detonate a high explosive.

Detonating Fuse

For shallow depths, say less than 3 m, and for small number of holes, a detonator is inserted in the cartridge itself and detonated by ignition of safety fuse or in the case of elec. detonator, by an exploder. For a large no. of holes blasted at a time in mechanised quarries and in U/G coal mines electric detonators are used. A deep hole in a quarry needs a long length of detonator leads and to avoid this it is common to use a detonating fuse like cordtex (trade name of ICL The fuse consists of a core of PETN enclosed in a tape which is wrapped with cloth. The fuse is then completely enclosed in a tubular cover of plastic material which is white for Cordtex and orange for Geocord detonating fuse (ICI). The detonating fuse looks like a plastic cord; its external dia. is about 5 mm and weight about 20 g per metre length. It has a velocity of detonation of 6500 m/sec. and it is practically instantaneous in its action.

Detonating Relays

In opencast workings, detonating relays using detonating fuse for initiation provide a non electric delay firing system. This method avoids the electrical connections which are required when using delay detonators. A detonating relay is essentially an assembly of two open-ended delay detonators coupled together with flexible neoprene tubing in an aluminium sleeve suitable for crimping into a detonating fuse.

BLASTING IN UNDERGROUND COAL MINES

Blasting in underground coal mines is a specialised operation. The proper use of explosives is vital to safety, influences the cost of production, and in many cases, has a direct bearing on the quality of the coal produced. The possible occurrence of highly inflammable mixtures of methane and air and exposable dusts has led to special statutory requirements for explosives and their use in such mines.

Basically two methods of working are followed in coal mines - Room (also called **Bord**) and Pillar, and **Longwall** Methods. Different blasting practices are followed in the development stage and in removing pillars so formed.

In drives or in mining out a room, the coal is cither blasted **off the solid** where the coal is blasted from the solid seam which has but **one free face**, or **cut coal** is blasted in which the seam has previously been cut to provide at least one more free face.

Blasting off the solid (Solid blasting)

The first essential in the technique of drilling and blasting solid coal development headings is to create a free face for the explosive to blast into. The holes (which will form the CUT) are drilled so that relief of burden is towards the free face. The remaining holes in the round are drilled so that they break towards the cut. Short delay detonators are used to control the sequence of firing of holes. The maximum burden placed on shot holes with this method should not exceed half their depth and normally, is established by field trials since breakage characteristics vary from seam to seam. Holes should be spaced to ensure that one does not rob the other and that the explosive charges will be adequately confined for maximum efficiency and safety.

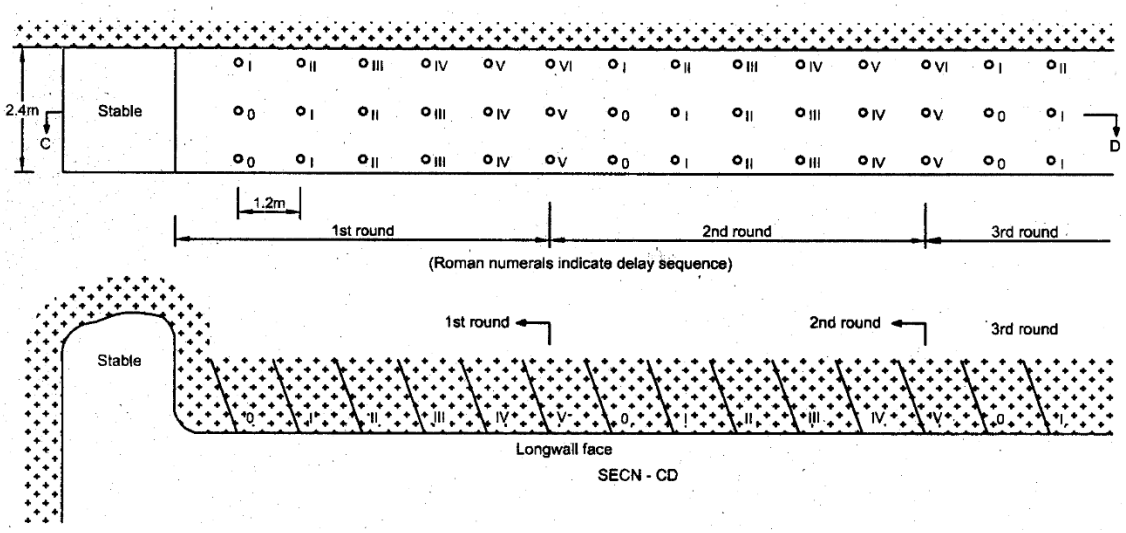
Three methods of solid blasting off the development headings have been successfully used.

- **Wedge cut pattern** In wedge cut or V-cut pattern 'breaking in', 'cut' or 'opening' holes are drilled towards each other to form a wedge, the angle and depth of which depends on the prevailing conditions, hardness of coal etc. The wedge cut pattern will reduce the number of delays needed.

- **Fan cut pattern** In fan cut method, the holes are drilled in a fan like pattern initiating the shortest holes first with the delay sequence rising towards the longest holes.
- **Drag cut pattern** The drag cut is in effect a type of 'vertical' fan cut in which pairs of holes are drilled towards either the floor or the roof of the excavation. This pattern is less commonly used.

Blasting on Longwall face

On a longwall face, the shotholes are drilled at an angle of 45°-60° to the face; a coal face 2.4 m high requires 3 rows of holes and distance between holes in the same rows of holes should be nearly 1.2 m. A typical layout of shotholes on a longwall coal face for blasting off the solid is shown in following figure.



Depth and pattern of blast holes

The depth of vertical blast holes in coal is generally equal to the height of the bench. In hard rock like sandstone, laterite, hematite, etc. the depth should be 0.5 to 1 m deeper below the level of bench floor. This loosens the toe. In any case, the hole should terminate in hard rock and not in the soft one; otherwise the force of explosive is wasted.

Burden is the minimum distance from the face to the blasthole (the term usually refers to burden at the top of the face).

Toe is the projection of the bottom of a face beyond the crest. Sometimes the bottom edge of the bench is referred to as toe.

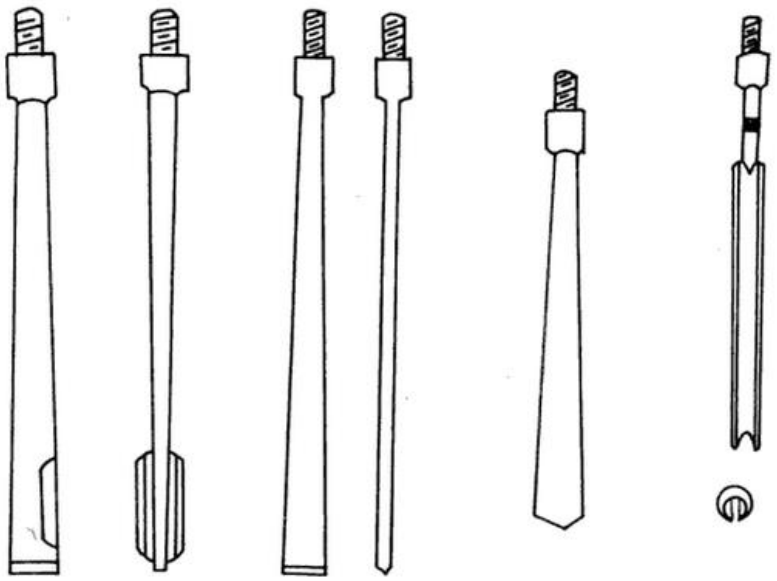
In hard rocks like laterite and hematite the spacing and burden vary from 0.3 to 0.4 times the height of bench. In less hard rocks like coal and sandstone, the spacing and burden vary from 0.5 to 0.8 times the height of bench. The exact dimensions depend upon the hole diameter, type

of explosive used, type of the rock, nature of rock consolidation and the angle of cleats or laminations with the blast hole.

DRILLING

Percussive Drilling

It is the oldest method of drilling. In this method a great variety of bits suspended from cables or rods have been used to bore through different kinds of rock. Rope boring was widely used for oil well drilling in which they raised a heavy blunt chisel type of bit jumping on the end of a cable. This enabled a great speed in fairly hard rocks. This blunt type chisel bit is not suitable for clays and soft marls which not only cushion the blows but ball up the bit until it attains a sucking action that renders the bit almost useless. For soft mudstones and shales a long heavy and narrow tool proved successful. In some cases, a bit of fish-tail pattern was used in soft but less sticky formations. But for harder rocks the chisel type bit or blunt faced heavy chisel bit was the one most used today in percussive drilling. Following figure shows different types of bits used in percussion drilling.



Different types of drill bits used in percussive drilling

Percussive method of boring is particularly suitable for drilling in heterogeneous glacial deposits and other stony overburden, or where hard quartzite pebbles are so loosely set in a matrix of soft sand that they become like a broken ball rock and are often very destructive of any kind of rotary bit, diamond or otherwise.

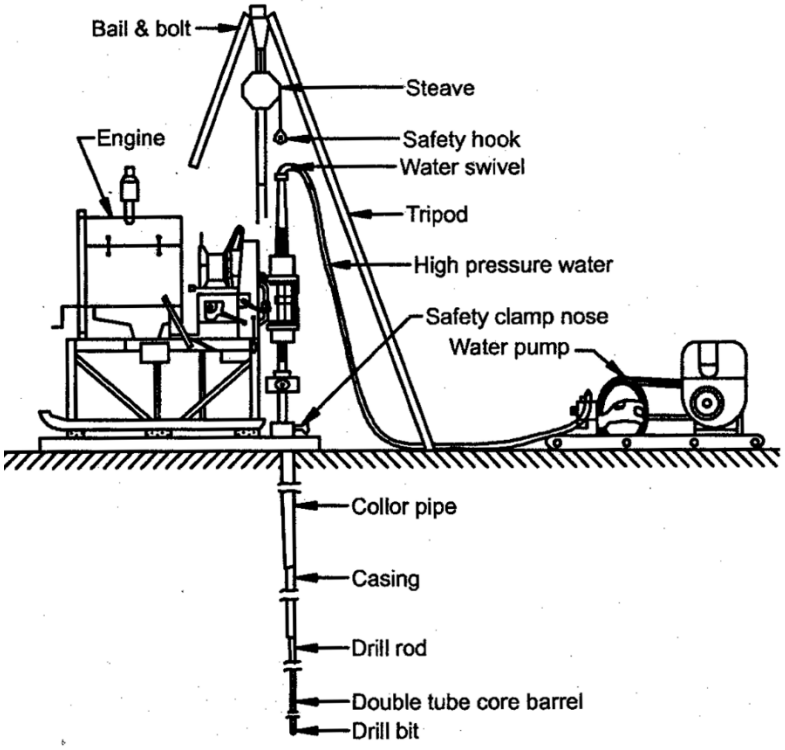
This method is at its best in *rocks which fragment well under blows*. It requires less quantity of water, just sufficient to make the debris into a slurry which can be removed by a sludger. But

with this method of boring samples are often contaminated by a portion of higher strata dislodged during the drilling process.

Diamond Drilling

The surface arrangements for diamond drilling include, as shown in given figure.

- a derrick,
- an engine for supplying power,
- an winch,
- a pump for supplying water under pressure for flushing,
- a setting tank,
- a platform for keeping the drilling rods lifted for removal of core or changing the bit,
- core boxes for keeping the cores, and
- a driving and feed mechanism for the drill rods.



Surface arrangement for rotary drilling

The diamond drill bit is rotated at a speed of nearly 300 r.p.m. and the pressure on the diamonds is between 1.5 and 2 kgf/cm^2. The pressure acting upon the diamonds of the drill bit and the rate of advance of the drill bit into the rock are controlled by an arrangement known as "*feed mechanism*". The feed mechanism is hydraulic for deep holes, but may be replaced by

screw feed for shallow holes. Beyond a depth of nearly 60 m, the weight of the rods keeps the bit pressed against the rocks and the feed mechanism may not be necessary. At greater depth the feed mechanism is operated in such a way that the weight on the drill bit is not excessive.

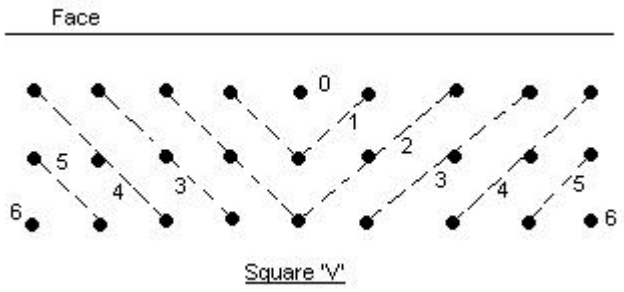
Drilling Patterns

V, V1, V2 Patterns

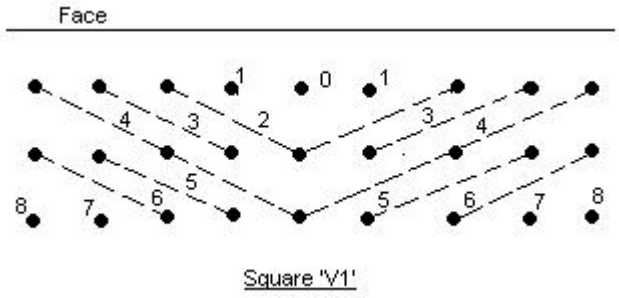
These Pattern are far superior, to row delays. These result in superior fragmentation due to reduce hole burdens and increased spacing at the time of hole initiation and also due to in-flight collision of broken rock during its movement. The delayed action of holes in the back row reduces over break ensuring increased wall stability.

The best available pattern is one where the holes are drilled (staggered) on a equilateral triangle pattern. This in a drilled spacing to burden ratio of approximately 1.16. It has been observed that an effective spacing (Se) to Burden (Be), ratio of about 3.5 is achieved with holes drilled on an equilateral triangle grid and fired using a V1 initiation sequence.

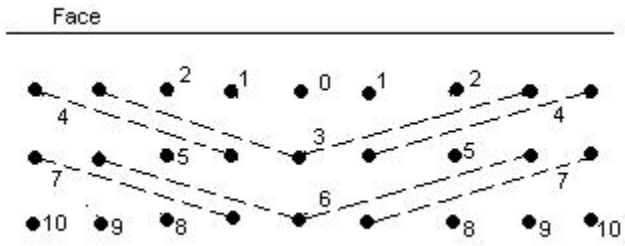
Drilling (staggered) equilateral triangular pattern require more operator skill and supervision as compared to in-line patterns. Clear marking of the hole positions in advance by a responsible person would help the drillers immensely. Fig. gives various delay patterns discussed above.

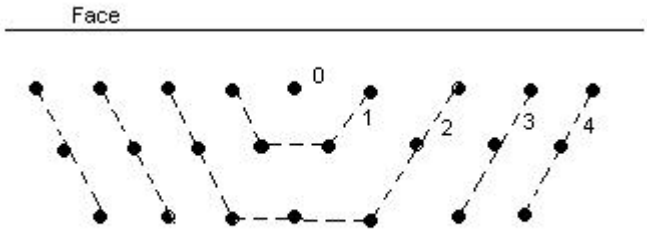


Square 'V'

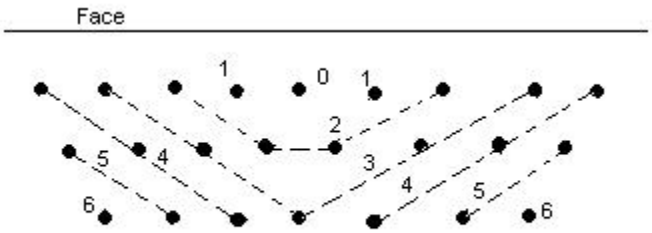


Square 'V1'





Staggered 'V'



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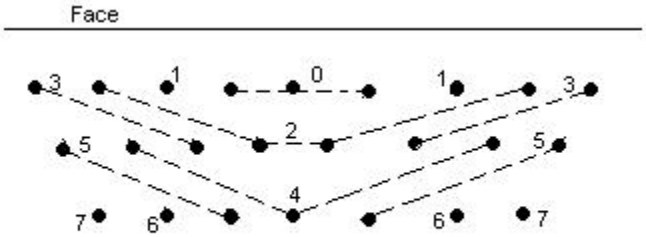


Staggered 'V2'

Down the Hole (DTH) Drill

"Down the Hole" or "DTH Hammer" drill is meant for drilling borehole in hard compact rock formation. It combines both percussion and rotary action and powered by compressed air. If required, DTH units are provided with mud pump for negotiating the loose overburden. The hole diameter varies between 115 and 165 mm for a depth of 125 m. The drilling tool is a cross

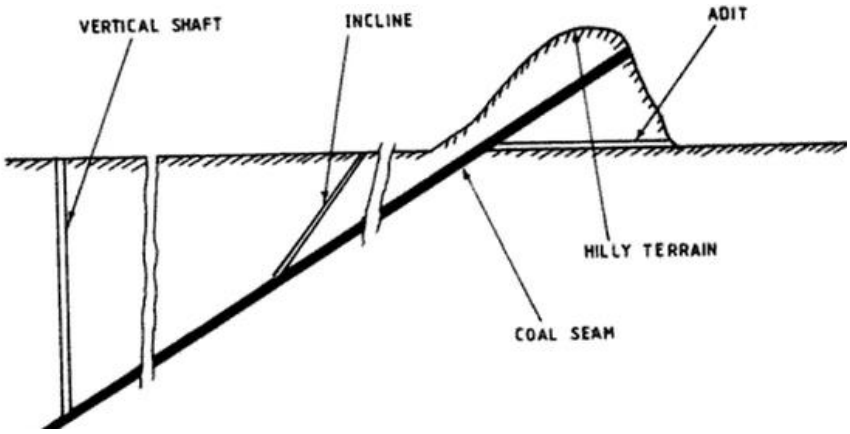
bit or a button bit. In DTH hammer drill the assembly of the drill bit and its short-length pipe is called the DTH hammer. The lowering and hoisting of the drill rods are operated by a chain.

The drill is levelled with three hydraulic jacks. The drilling is usually vertical with a possible swing of 20 on either side from vertical in some model. DTH hammer rock drills have been leading the way in performance, reliability and longevity since their introduction 15 years ago.

MINE ENTRIES

The term opening up of a coal seam means establishing access to a coal seam and necessary development work for its exploitation. A seam can be worked by open pit mining or by underground mining methods. Seams which are worked by underground mining methods can be approached by shafts and or inlines or surface drifts or adits depending on the geology and topography of the mine area. The most common means of approach are by surface drifts or shafts or a combination of both and in a few situations the seam is reached by an adit.

Following figure illustrates the various means of access.



In the case of deposits worked by open pit mining method, opening up of a coal would comprise driving of haul roads to the coal seam and forming benches for the removal of overburden and coal.

The comparative advantages and disadvantages of drifts and shafts are given below:

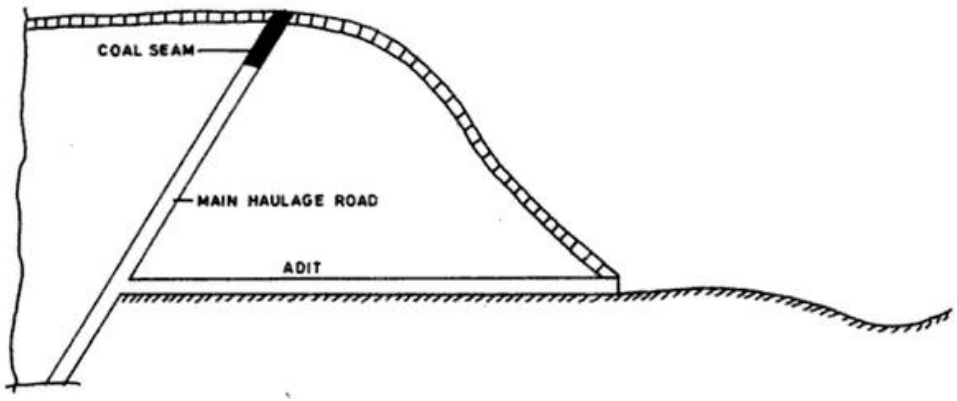
- The time required for reaching full production is very much less when the mine is opened out by drifts.
- The capital cost of driving and equipping a drift may be 50 % less than that for sinking and equipping a vertical shaft. .
- With drift entries it is possible to design continuous conveyor transport directly from the coal face to the surface plant. In shafts the flow of coal to the preparation plant is intermittent. Also by continuous conveyor transport in drifts, their is no need of filling coal in tubs or mine cars as in shaft winding and hence coal degradation is reduced.

- Power costs are low in drift transport.
- The capacity of drift is very large compared to the capacity of shafts.
- As for winding men, shafts have high capacity and shortest time between surface and pit bottom. The drifts can have capacity similar to shafts but the time for transport of men between the pit top and the seam level is greater.
- The operational cost of drifts are low.
- The transport of material to the pit bottom is steadier in shafts but slower in drifts. In the case of drifts, however, the transfer of material from the drift haulage to the pit bottom haulage is simpler than from shafts. In shafts larger equipment can be lowered, whereas in drifts the size of equipment is limited by the size of drifts though commensurate to the size of underground roadways.
- The resistance offered to the passage of ventilating air is less in shafts. Hence, the power costs for ventilating a mine are less with vertical shafts than with drifts. Shafts also allow better arrangement of electric cables, water and compressed air pipes, etc.
- There is greater possibility of a drift passing through an unfavourable geological conditions because the drifts have longer length.
- The loss of coal in protective pillars is much greater for inclined drifts than for shafts.
- Drifts present less environmental problem than shafts because of their lower profile on the surface and also screening of the site by bunds and trees is much easier in the case of drifts.

ACCESS BY ADITS

Adits are level or nearly level drifts driven from the surface to access the seam. The following conditions favour the opening up of a coal seam by adits:

- The coal seam should occur in a hilly terrain and the topography should be such that a level drift driven from the foot of the hill can cut the seam, (see figure).

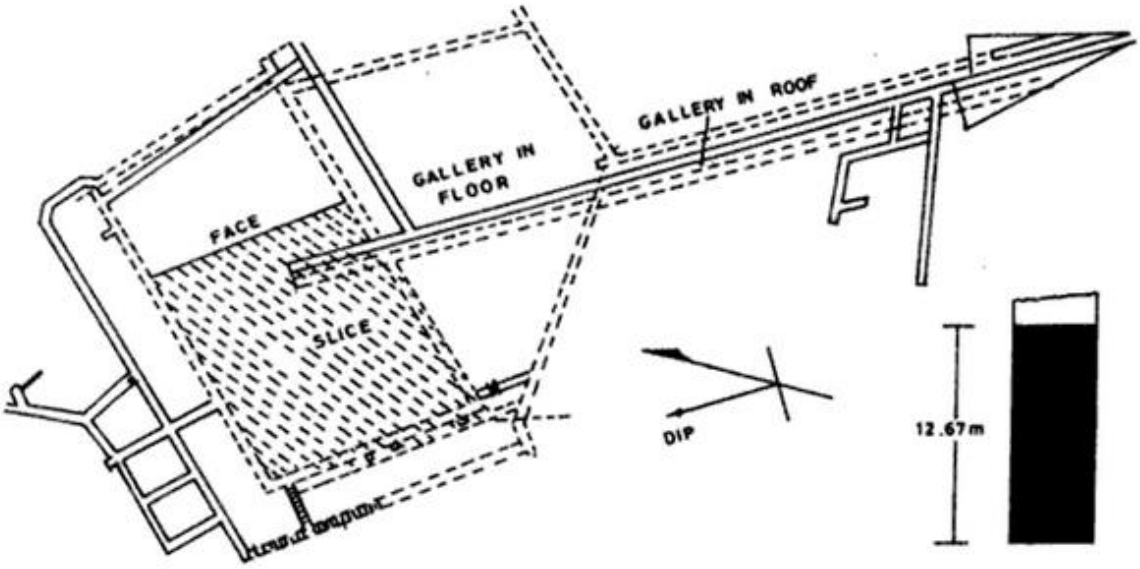


- The coal outcrop should be above the level of the loading point; and
- Sufficient space should be available at the mouth of the adit to facilitate the construction of coal preparation and handling plant, etc.

OPENING UP BY SURFACE DRIFTS OR INCLINES

Inclines are one of the simplest methods of opening up coal seams in the early stage of development. Inclines are driven from the surface at an angle of normally not exceeding 1 in 4. If the coal seam is outcropping, the incline may be driven after the outcrop coal has been worked out by opencast mining but in that case excavated area unless filled by overburden, forms a large water reservoir and may cause inundation of underground workings unless substantial barrier of coal has been left against the possible water standage.

At least two inclines have to be driven to the seam to provide separate means of ingress and egress and also to provide separate roads for intake and return. In some situations a third incline is also driven to provide for travelling roads. An example of opening up a 12.4 m thick seam by three inclines is illustrated in following figure.



After the incline touches the seam and it has been further driven along the dip or apparent dip of the seam for some distance, level roads are driven on its either side and development work starts.

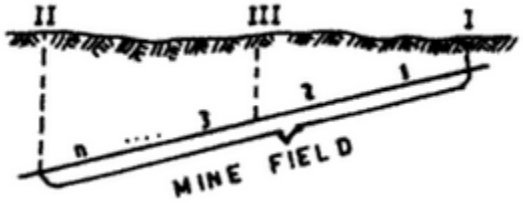
Fresh air is taken down the dip through one incline and return air is brought out of the mine through the other incline. In some cases an air shaft is also sunk to facilitate ventilation.

OPENING UP BY VERTICAL SHAFTS

When the depth of the coal seam is more than the depth up to which mining can be done by surface drifts economically, the seam is approached by shafts.

At least two shafts must be sunk to provide separate means of egress and ingress and in some situations more than two shafts are considered desirable and necessary, e.g. in stowing pits at some mines a third shaft has been sunk at the rise boundary through which sand/water slurry is brought in the mine.

On the dip and rise centre line of the take there could be three possible positions of the shaft. They are: (i) at the extreme rise; (ii) at the extreme dip, or (iii) in the centre (see following figure).



Position I is advantageous in that the depth of the shaft is minimum and. therefore, cost and time of sinking to the seam are also minimum. But to develop the property a long incline will have to be driven. In position II the cost and time of sinking are maximum and also the cost of pumping water and hoisting are maximum. Taking all aspects into consideration shafts sunk at position III will offer advantages.

HORIZON MINING

Horizon mining is a system of mining in which coal seams are opened up by level roads driven in the rock. The system consists of more than one level. Here level means all main and secondary roads driven at the same depth or in the same horizon.

Horizon mining system is normally applied to the mining of the steeply inclined seams with gradients in excess of 15°, but when the gradient is between 5° and 10° it may or may not be applied and in case the gradient is up to 5°, the system need not be applied.

Mining After the vertical shafts have been sunk two sets of roadways are driven in stone in each horizon or level' (i) Laterals parallel to the strike, and (ii) crosscuts at right angles to the strike. The main lateral drift connects the crosscuts with each other and the shafts. In most of the mines laid out on horizon system of mining there is only one lateral but circumstances may necessitate more than one lateral road.

SHAFT SINKING

To extract mineral by underground methods of working, the access may be by an incline (a tunnel from surface to the mineral bed), by an adit, or by a well which is called **shaft** or pit in mining terminology.

Shaft sinking is costly operation. The mining companies pay to the shaft sinking contractors amounts varying from Rs. 5 lac- 10 lac per metre of overall depth of the shaft sunk and this amount includes sinking, lining with concrete, head gear, winding engine, compressors and all the machinery required for sinking and lining upto the final depth (A turnkey job).

Equipment

The surface plant and equipment required for sinking is as follows:

- Steam boilers or diesel engines for winding engine, pumps, etc. unless electric power is available.
- Winding engines and winders fitted with locked coil ropes.
- Steel headgear. The headgear map be temporary nature and after the sinking is over, it is replaced by a permanent headgear and permanent winders to suit the output.
- Double drum winches for walling scaffold, and other winches for lighting cables, shot-firing cables, pump suspension ropes and pump cables.
- Air compressors for jack hammer drills used for drilling into rock and other compressed air operated equipment.
- Fan of nearly 300 m3 per minute capacity.
- Generator with diesel or steam engine for lighting.
- Folding doors to cover the shaft top.
- Shaft centering arrangement.
- Signalling arrangements from pit bottom to pit top and u?w pit top to winding engine.
- For disposal of debris, chutes, buckets, and tipping tubs with tramline, etc.
- Workshop including smithy shop, mortar mill and other usual machines.
- Lamp room, first aid room, magazine, stores, office, etc.

Temporary Lining

It is necessary to support the sides of the excavation to prevent their collapse. A heavy wooden frame or a frame of steel girders is built across the shaft top from which the first (topmost) ring of temporary lining is suspended.

Permanent Lining of shaft sides

When strong rock is reached, the excavation is reduced to the finished diameter of the shaft and continues thus for 3 to 4 m below. Arrangements are then made for construction of permanent lining which may be of brick, concrete etc.

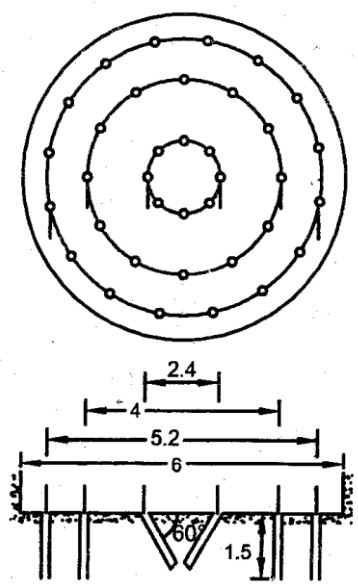
Brick walling is a common practice for ordinarily compact and moderately walling is a common practice for ordinarily compact and moderately wet strata.

Blasting in Sinking Shafts

Although full diameter drilling of shafts has been done in many countries abroad, the normal technique of shaft sinking is *drilling*, *blasting* and *mucking*. The progress of shaft-sinking as in tunnelling is dependent largely on the efficiency of drilling and blasting. A ring of cut holes which are inclined towards the centre are blasted first in the centre which form an inverted pyramid. This is followed by easers and trimmers, the number of rings of easers depending on the diameter of the shaft.

As sinking shafts are normally wet, it is important to use high density, water resistant explosives such as special gelatines, Ajax 'G' and the like.

The hard rock in a sinking pit is blasted with explosives after holes are drilled. The shot-holes are arranged as shown in the given figure.



Blast holes in a sunken shaft (dimension in metres)

As a thumb rule it may be stated that the number of holes in a ring is three times the diameter of the ring in metres.

The holes are drilled by hand-held jack hammer drills operated by compressed air.

Blasting of the inner ring is to be carried out first and all the shots in the ring are connected in series.

The shots are connected to a shotfiring cable which is suspended from a reel at the surface. All men are withdrawn, the folding doors closed, and the shots are fired electrically from the surface by a hand operated heavy duty exploder.

When the debris resulting from the blasting of inner ring is being cleared up, holes of outside sumper ring are charged and in this manner the blasting of all the rings is carried out.

TECHNICAL TERMS IN COAL MINING

Seam

A seam is assumed to be thin if normal thickness is less than 1.5 m; moderate if between 1.5 m and 4.5 m; thick if between 4.5 m and 9.0 m and very thick if beyond 9 m.

Stratum

The stratum is referred to as flat if general inclination does not exceed 5° to die horizontal; inclined if it is between 5^0 and 18^0; steep if it is between 18° and 40° and very steep if inclination is beyond 40°.

Gallery

A road in a coal seam proper is called a gallery.

Dip or Dip gallery

A road which is driven along the dip of the seam is called a dip gallery and sometimes only a dip.

Level or Level gallery

A road driven along the strike of a seam is called a level gallery or simply a level. A dip gallery may be along the true dip of the seam or along an apparent dip. A level gallery may not be truly along the strike of the seam but may slightly rising inbye, i.e. towards the working face, for considerations of haulage and drainage.

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Drift or Stone Gallery

A roadway in stone connecting two ore more coal seams is called a drift. It is sometimes referred to as stone gallery if only one of the ends of the road is in coal and the other is a blind end.

Pillar

A solid block of coal surrounded on all sides (or nearly all sides) by galleries is known as pillar. It forms the natural support of the roof in a mine.

Crosscut

Where the galleries in a seam are generally along the dip-rise and strike forming square or rectangular pillars, a gallery which cuts across the pillars, due to its drivage along an apparent dip, is called a crosscut. Such crosscuts are sometimes required for facility of ventilation, drainage, haulage or stowing.

Heading

A gallery in the process of being driven is called a heading. The moving front of any working place on the inbye end of any gallery, roadway or drift is called a face. A face in coal is also called a working place or simply a working.

DRIVAGE OF GALLERIES IN COAL

The methods commonly employed for drivage of galleries in coal are :

- mechanical method of drivage with coal cutting machines and drills.
- mechanical method of drivage with heading machines which cuts and load the coal, like the continuous miner, coal auger, and road header.

Galleries are usually driven in pairs or sets of 3, 4, or 5. From considerations of ventilation drivage of minimum two galleries is essential unless the gallery has to go only a small distance. Drivage of galleries by coal cutting machines and coal drills is a common practice for quick progress of headings, large output and fast development of the area. When coal cutting machines are used the operations at the face require.

- giving a cut by the coal cutting machine,
- drilling of shot holes.
- charging with explosive and blasting,
- dressing of roof and sides to render them safe,
- loading of coal into tubs, mine cars or conveyors.
- dressing of sides, roof and floor to make the face ready for the next cut.

Skid mounted coal cutting machines were used in bord and pillar method of mining (mostly under-cutting machines) for a cut at the face to provide a free face before blasting. The introduction of explosives for "solid blasting" eliminated the need to have a "free face" resulting in gradual disappearance of coal cutting machines from the mines.

Support

The coal pillars formed during drivage of galleries form the natural support. Where the roof is bad wide junctions should be avoided and level galleries on either side of a main dip should be staggered.

Drainage

Drainage of water in the mine is effected by pumps which are designated as follows depending on the location of their installation.

- Face pumps,
- Stage pumps,
- Main pumps.

The face sump is of a temporary nature and has a small capacity as the face has to progress daily. The sump serves one week where the face advances 9 m to 12 m per week.

The pump discharges water into the sump of semi permanent pump on the outbye side, called the stage pump, which delivers water to the main pump.

Transport

The common mode of transport in majority of our mines is rope haulage, though scraper chain conveyors, belt conveyors and locomotives have been introduced in some mines. The transport used for an advancing heading should be capable of providing transport facilities near the advancing inbye faces. Direct haulage suits well in this respect for the advancing and the tail rope haulage for the rise headings. For level headings endless rope haulage is the common practice when the roadway is nearly 100 m or more in length, the shorter distances being covered by hand tramming before installation of haulage.

Two tracks, one for the load and the other for the empties, are always essential at the loading points at the face. The haulage tracks should be as near the face as possible for convenience of loaders and to avoid expenses on lead. When driving two or more headings a skid mounted machine has to pass in the space between the track and the pillars.

Scraper chain conveyors can be readily kept close to the face, within shovellable distance, by addition of pans. The scraper chain conveyor may deliver coal into tuvs or into a belt conveyor.

TUNNELLING

Bored Tunnelling by Tunnel Boring Machines (TBM)

Bored tunnelling by using a Tunnel Boring Machine (TBM) is often used for excavating long tunnels. An effective TBM method requires the selection of appropriate equipment for different rock mass and geological conditions. The TBM may be suitable for excavating tunnels which contain competent rocks that can provide adequate geological stability for boring a long section tunnel without structural support. However, extremely hard rock can cause significant wear of the TBM rock cutter and may slow down the progress of the tunnelling works to the point where TBM becomes inefficient and uneconomical and may take longer time than the drill-and-blast tunnelling method.

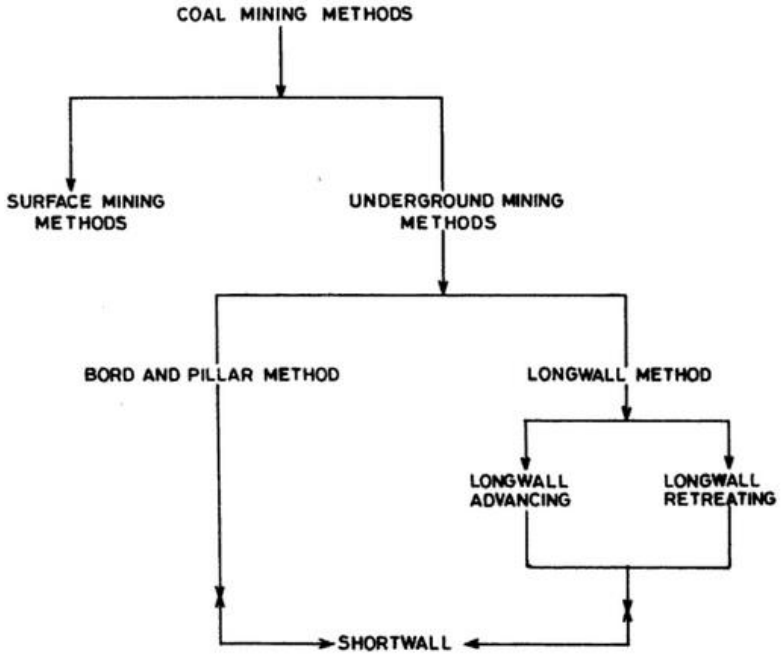
UNDERGROUND MINING METHODS

There are two basic underground coal mining methods.

They are:

- bord and pillar method, and
- longwall method.

Although the basic principles remain the same, there could be many variants of these two methods (see following figure)

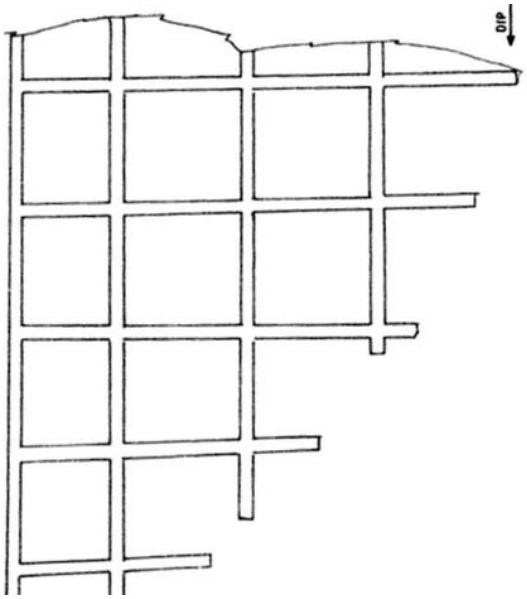


Basic methods of mining

Combining the main features of both longwall and bord and pillar methods, there is yet another method of mining coal seams which is known as "shortwall method" of mining. It incorporates the advantages and disadvantages of both bord and pillar method and longwall method.

Bord and Pillar Method

Fundamentally, the bord and pillar method of mining coal seams (see following figure) involves the driving of a series of narrow headings in the seam parallel to each other and connected by cross headings so as to form pillars for subsequent extraction, either partial or complete, as geological conditions or necessity for supporting the surface, may permit. Ideally, the pillars should be square but they are sometimes rectangular or of rhombus shape and the galleries surrounding the pillars are invariably of square cross-section.



Bord and Pillar method

The bord and pillar method of mining is suited to work flat coal seams of average thickness and at shallow depths. Coal seams of 1.8 to 3 m thickness are best suited for this method, though the method has been successful in thinner seams also down to a thickness of 1.2 m and in thicker seams up to 4.8 m in thickness.

In seams with gradients of more than 1 in 4 difficulties are encountered in manoeuvring machines. Most of the bord and pillar method of coal mining has been done in depth range less than 300 m as at greater depths pillars experience crush. However, in India in some cases the depth of mining by bord and pillar method has been around 600 m, though mining at such depths is beset with the problems of strata control.

The bord and pillar system of mining can be done in three ways, namely :

- Develop the entire area into pillars and then extract the pillars starting from the boundary.

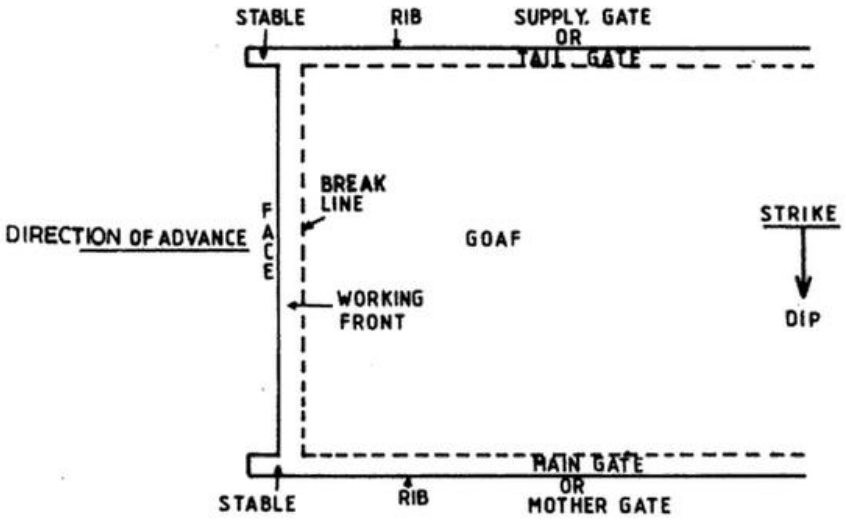
- Develop the area into panels and extract pillars subsequently panel-wise. This is called panel system of mining.
- "Whole" followed by "broken" working in which the mine is opened out by a few headings only and thereafter development and depillaring go on simultaneously starting from the boundary.

Longwall Method

Of late, the high productivity and production associated with longwall method of mining has made this method the most popular method of mining. Even in countries where longwall method of mining was not in practice, the current trend is towards adopting this method of mining.

A longwall face comprises the following elements (see figure).

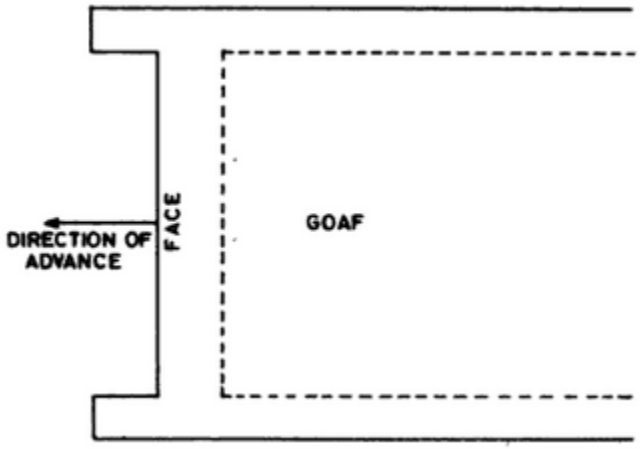
- **The Face** A long front from which the coal is won.
- **Tail Gate** The roadway usually used for the supplies of material and return air. It is also known as Supply Gate.
- **Main Gate** The roadway used for transport of coal out-bye and for the intake of air. It is also known as Mother Gate.



- **Goaf Line** The line at which roof is intended to cave.
- **Span** The width of the workings from the goaf line supports to the face.

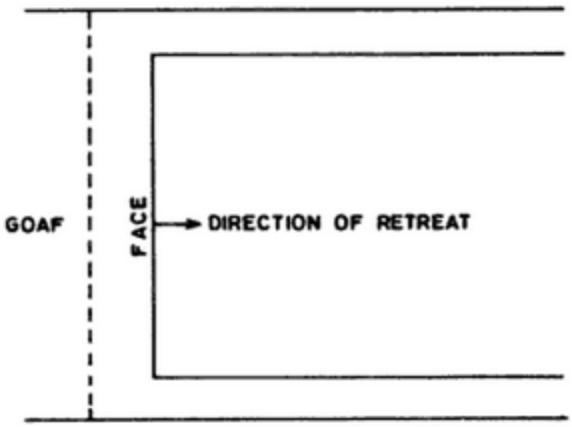
- **Stable** A portion at the ends of a face specially prepared to accommodate the machine to cut the face.
- **Buttock** The portion of the face at its end from where cutting starts.
- **Face Conveyor** The conveyor installed on the face.
- **Stage Loader** The conveyor which receives coal from the face conveyor for its transport out-bye.
- **Face Supports** The supports used on the face.
- **Breaking row Supports** The supports at the goaf edge.

The longwall method of mining coal involves the extraction of the panel of coal to be worked by advancing the face forward (in the case of advancing longwall) on a wide front leaving behind the roadways serving it which are supported by packs of stone or other packings in the area of extraction (see figure).



Longwall advancing method of mining

In the case of retreating longwall (see figure below) the face is retreated on the roadways driven before opening out the face and as the face is retreated backwards, the goaf is allowed to cave in or it is filled and the gate roadway is lost in the goaf.



Longwall retreating method of mining

This method can be employed almost in all geological conditions, though it is eminently suited for working thinner seams, i.e., seams less than 1.8 m thick. On the lower side, seams of up to 30-35 cm thickness have been worked by this method. Coal from a longwall. especially in a thin seam is the cheapest coal a mine can produce. It is also desirable that thick seams (more than 4.8 m) be worked by this method in slices of 2 to 3 m. It can be practised in seams at depth and also in gassy seams or seams prone to spontaneous heating.

The longwall mining finds easy application in flat to gently inclined seams say up to 1 in 3. In steeper seams faces must be arranged at an angle to the true dip or on strike depending on circumstances.

Coal seams with soft coals may be worked by longwall methods as pillars in bond and pillar mining may crush. Also seams with dirt bands can be worked by longwall method and the dirt can be disposed of and stowed in the goaf. In some seams floors have a tendency to creep and in such cases bord and pillar method is not suitable but longwall method can be employed as by good quality packing the tendency of the floor to creep can be reduced whereas in bord and pillar method, the presence of many roadways may aggravate the problem.

SURFACE MINING (OPENCAST MINING)

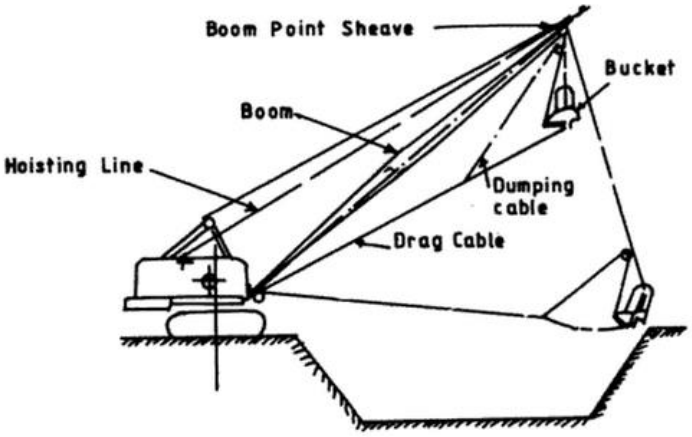
Opencast mining or quarrying of minerals is *easier* than mining by underground methods. During quarrying the alluvium and rocks below which the minerals lie, are removed and dumped, in the initial stages, in a place which is not required in future for quarrying, residential or other purposes. The mineral exposed is completely extracted. Opencast mining is also known as open-put mining, open-cut mining, surface mining and also as strip mining, the later term being commonly used in the U.S.A. for opencast mining of coal. The overburden and the mineral, coal, are excavated in long strips of a few metres thickness and hence the operations are termed strip mining.

The operation of removing overburden and extracting mineral is done by one of the following methods.

- **Manual quarrying** In this case manual labour is employed. Small drilling machines, drilling 1.2 m to 1.8 m deep holes, 37 mm diameter, are used and the holes are blasted with gun-power or other explosives. The overburden and mineral are manually loaded into tubs which are hauled by rope haulages or locomotives. Tipping trucks are also sometimes employed and manually loaded.
- **Mechanical opencast working** In this method heavy earth moving machinery like draglines, power shovels, rear-dumping trucks, well-hole drills etc. are used. The blast holes are 6 m to 18 m deep, and 125 mm to 250 mm diameter. The rock is blasted by liquid oxygen, open cast gelignite or other high explosives. Mineral and overburden are transported by locomotives, belt conveyors or large trucks known as dumpers. Bucket wheel excavators are used in some mines for soft rocks e.g. at Neyveli lignite project.

Drag Line

A drag line is a machine used for excavating earth, sand or soft rock and consists essentially of a revolving deck, a long light boom, crawler chains, and a special type of bucket held in position and controlled by cables (see figure).



The bucket, when it has to be loaded, is lowered in the earth or loose rock by manipulation of the cables and is dragged by them. As it is dragged it gets loaded. Hence the name dragline. A dragline is operated by diesel engine or a motor which is supplied power at high voltage from external source through a trailing cable. The depth to which a dragline digs is limited by the capacity of the drums to hold the hoist cable. When digging, the bucket, after it is loaded, is hoisted up, the boom given a swing through 90° and the contents then unloaded by manipulation of the cable.

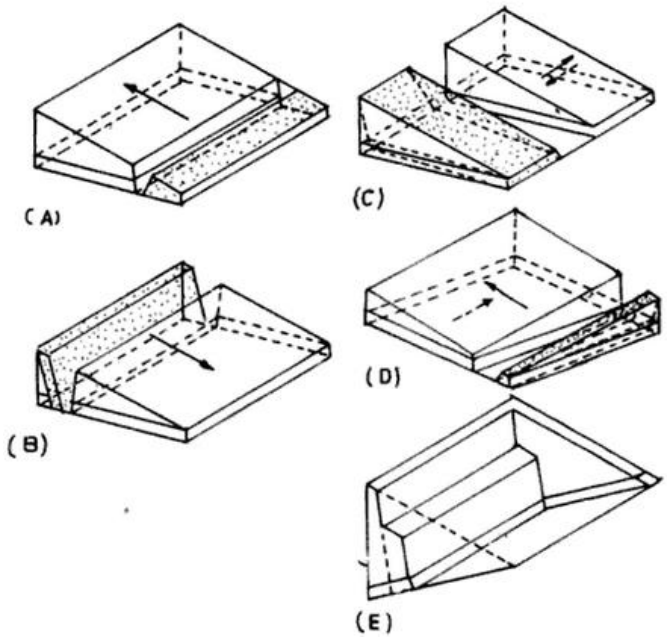
A dragline is suitable for digging alluvium, sandy soil, unconsolidated rock or blasted coal/rock. It digs below the level, at which it stands and from position can dig over a wide working place and cast the earth over a wide area within the reach of the boom. It is generally not employed to load dumpers as the accurate positioning of the dragline bucket over a limited area of the dumper delays the cycle of operation and the common application is for dumping overburden. It is suitable for working a quarry with watery conditions as the dragline works from a higher and, therefore, dry position.

A drag line may be crawler mounted or of waling type. Crawler mounted machines have travelling speeds of 0.25 to 5 km/hr. A walking dragline has a travelling speed of 0.18 to 0.06 km/hr.

Front-end Loader and Wheel Loader

Front end Loader

A Front-end loader (see following figure) is a wheel tractor with a loading bucket mounted on the front.



(a) Strike Cut With Down Dip Advance (b) Strike Cut Up Dip Advance (c) Dip Cut With Strike Advance (d) Diagonal Cut (e) Open Pit Operation

These machines are efficient for loading coal from thin scams, say 0.3 to 3 m thick where it becomes necessary to gather coal before loading. They have high mobility and can operate under favourable conditions with high productivity. They also find increased application in contour stripping for load and carry operations over short distances.

Front-end loaders are normally diesel powered, bin all-electric front-end loaders are now available.

They are ideally suited as a loader for well fragmented ground on good under footing. They are also used in haul road maintenance, stockpile reclamation clean up in the pit and as a back up machine.

Wheel Loader

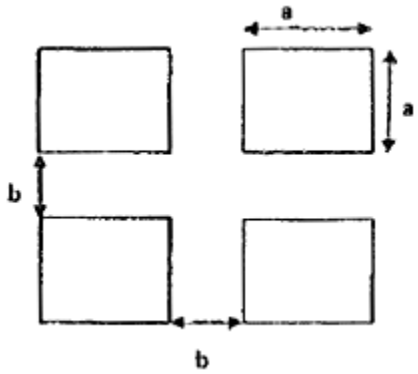
Wheel loaders are tyre mourned machines and all types, whether small or large offer several advantages, e.g.. high productivity, transportability and versatility and high utilisation.

SOLVED NUMERICAL PROBLEMS

Example

A bord and pillar panel having square pillars is designed for 30% extraction during development. If the gallery width is 5 m, the side of the pillar in m is _____.

Solution



Extraction ratio

$= 1 - [a^2/(a + b)^2]$

$\therefore \quad 0.30 = 1 - [a^2/(a+5)^2$

Solving a = 25.6 m

Example

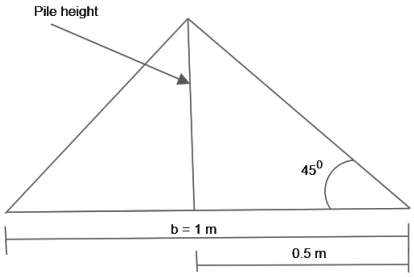
What would be the capacity of a flat belt conveyor in ton/ hour, if the bulk density of material is 0.8 t/m^3, belt width is 1.0 m, angle of repose is 45° and velocity is 100 m/min?

Solution

T = abv

= (1/2)(width x pile height) x b x v

where b is bulk weight and v is velocity.



Pile height = 0.5 $\tan 45^0$ = 0.5 m x 1 = 0.5 m

T = (1/2)(1 m x 0.5 m) x 0.8 t/m^3 x (100 x 60 t/hr) = 1200 t/hr

Example

A mine is being developed by bord and pillar method with a gallery size of 4.8 m x 2.4 m. The mine operates in 3 shift per day and 6 faces are blasted per shift. The average pull per round of blast is 1.2 m and the bulk density of the coal is 1.4 tonne/cu.m. If the OMS is 2.5, then the average manpower deployed in the development section per shift is ____

Solution

Total volume of coal

= Number of shifts x gallery width x gallery height x Average pull x Number of faces

= 3 x 4.8 m x 2.4 m x 1.2 m x 6 = 248.8 m^3

Weight of coal/day

= volume x density

= 248.8 m^3 x 1.4 = 348.3 t

Total manpower = Weight per day/OMS

= 348.3/2.5 = 139.3

Manpower per shift = 139.3/3 = 46.4

Example

A coal heading 4 m wide and 2.5 m wide has an advance of 1.0 m per cycle. The amount of explosive used in blasting is 6 kg. Taking specific gravity of coal as 1.5, the powder factor is ____

Solution

The powder factor, also known as the powder ratio, is a measure of the efficiency of blasting operations and is calculated as the ratio of the mass of material excavated (tonnes) to the mass of explosive (in kg) used.

Mass of excavation = volume x density

= (4 x 2.5 x 1) x 1.5 = 15 t

Mass of explosive = 6 kg

Powder factor = mass of excavation (t)/mass of explosive (kg) = 15/6 = 2.5

Example

A surface coal mine is worked by 12 m^3 shovel – 100 tonne dumper combination. If the shovel bucket fill factor is 0.8, the material swell factor is 0.75 and the average in-situ sp.gr. of the material is 2.8 tonne/m^3, the number of shovel bucket loads required to fill a dumper will be nearly ____

Solution

Bucket loose volume = 12 x 0.8 = 9.6 m^3

This is Volume of material as it sits in the bucket (before swelling).

In-situ weight of material per bucket

= 9.6 x 2.8 = 26.88 tonnes

Number of loads = dumper capacity/(swell factor x in-situ weight)

= 100/(0.75 x 26.88) ≈ 5

The swell factor usually means that the loose volume taken by the shovel is less than the in-situ volume.

Example

A double ended ranging drum shearer operates in a longwall retreating panel.

The following data are provided:

Face length : 200 m

Average cutting speed : 1.5 m/min

Web depth : 0.6 m

Average flitting speed : 4.0 m/min

Cutting height: 2.5 m

Number of shifts/day : 3

Density of coal : 1.4 tonne/cu.m.

Method of cutting is unidirectional and each shift requires a non-operational time of 2.0 hours.

The production per day in tonne (rounded off to one decimal place is ____

Solution

Daily production of shearer in tonnes = (number of shift) x (two full face cuts) x (face length) x (face height) x (web depth) x (unit weight of coal)

= 3 x 1 x 200 x 2.5 x 0.6 x 1.4

= 1260 t

Example

In a blasting round for drivage of a 3.2 m × 3.0 m cross-cut 20 nos. of 1.8 m long holes are used. If the average pull is 1.5 m and the in-situ density of rock is 2.78 tonne/m^3, the yield per detonator will be approximately ____

Solution

Total volume of coal

= gallery width x gallery height x Average pull

= 3.2 x 3 x 1.5 = 14.4 m^3

Weight of coal (t) = volume x density

= 14.4 x 2.78 = 40 t

Number of detonators = 20

∴ Yield per detonator = weight of coal/number of detonators = 40/20 = 2 t

Example

RMR of immediate roof in an underground mine 55. For 3 m wide gallery the rock load will be approximately ——. Given, roof rock density 2.5 t/m^3.

Solution

Rock load = W x D x (1.7 - 0.037 x RMR + 0.0002 x RMR^2)

= 3 x 2.5 x (1.7 - 0.037 x 55 + 0.0002 x 55^2)

= 7.5 x (1.7 - 2.035 + 0.605)

= 7.5 x 0.27 = 2.025 say 2 t/m^2

Example

If the bench height is 10 m, burden 4 m, spacing 5 m, sub-grade drilling 1 m, explosive per hole 110 kg, density of rock 2500 kg/m^3, then powder factor will be ____

Solution

Powder factor = blasted material (t)/explosive required (kg)

= spacing x burden x hole length x sp. gravity/explosive required (kg)

= (5 x 4 x 10 x 2.5)/110

= 500/110 = 4.54 say 5.

Example

A 15 cum dragline works for 30 days @ 6 hrs per shift and 3 shifts a day. The cycle time, bucket fill factor and operating efficiency are 50 s, 0.85 and 75 % respectively. What will be the total volume in cum handled by the dragline in a month?

Solution

Total volume handled by dragline

= 3600 x c_b x f x η/(t x swell factor) m^3/h

c_b = size of bucket in m^3 = 15 m^3

f = fill factor = 0.85

t = cycle time = 50 s

swell factor = 1 (assumed)

η = operating efficiency = 0.75

Total volume handled

= 3600 x 15 x 0.85 x 0.75/50 = 688.5 m^3/hr

Total volume in cubic metre

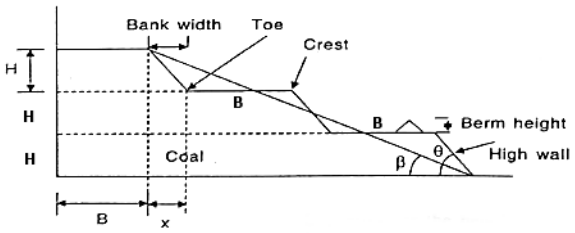
= 685.5 x (30 days x 6 hrs x 3 shifts) = 3,71,790 m^3

Example

Four benches are being worked by the opencast mining system. Height, width & face angle for each bench are 20 m, 60 m & 70° respectively. The overall slope angle of the benches in degrees is ____

Solution

See following figure



$x = H/\tan\theta$

Overall pit slope angle (β)

$$= \tan^{-1}\left(\frac{nH}{(n-1)B+nx}\right)$$

$$= \tan^{-1}\left(\frac{nH}{(n-1)B+\frac{nH}{\tan\theta}}\right)$$

where θ = slope of the bench

B = bench width

H = bench height

Given data:

n = 4

Bench width (B) = 60 m

Bench height (H) = 20 m

Slope of bench (θ) = 70^0

Putting these values in the formula

$$\beta = \tan^{-1}\left(\frac{4x20}{(3x60)+\frac{4x20}{\tan 70^0}}\right) = 20.9^0$$

Example

A surface mine blast design has 10 holes in a row. The length of blast hole is 9 m having a diameter of 200 mm. The spacing & burden are 6 m and 5 m respectively. The length of subgrade drilling is 1 m and the density of rock is 2.5 tonne/m^3 . Assume no back break and one row of holes is blasted . Considering an explosive density of 800 kg/m^3 and stemming length of 2 m, the powder factor from the blast in tonne/kg ____

Solution

Output per blast

= Number of holes x spacing x burden x density x (length of holes - sub grade length)

= 10 x 6 x 5 x 2.5 x (9 - 1) = 6000 tonnes

Explosive required per round of blasting

= cross sectional area of hole x number of hole x (length of hole - stemming height) x explosive density

= (3.14 x 0.2^2/4) x 10 x (9 - 2) x 800 = 1758.4 kg

Powder factor = output per blast in tonnes/explosive required in kg

= 6000/1758.4 = 3.41

Example

The sale value of chromite ore from an open pit mine is Rs. 7000 per tonne. Cost of mining, excluding stripping, is Rs. 2500 per tonne. If the cost of stripping is Rs. 1250 per m^3, the breakeven stripping ratio in m^3/tonne is ____

Solution

Break even stripping ratio = (recoverable price per tonne of ore - production cost per tonne of ore)/ cost of extraction per cubic meter of overburden material

= (7000 - 2500)/1250 = 4500/1250

= 3.6

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