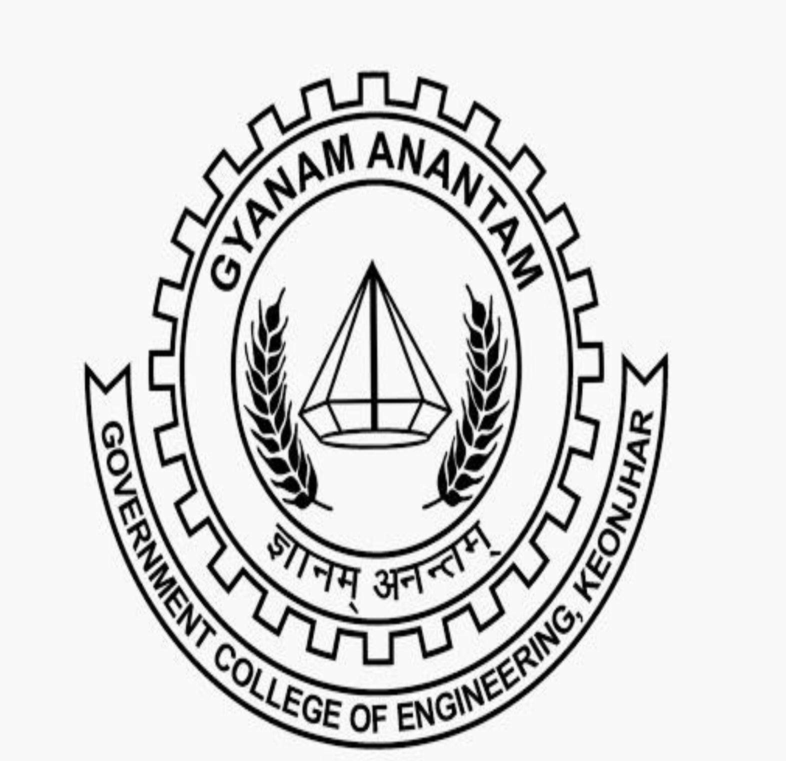
GEOLOGY-I

LECTURE NOTES



Compiled by

Bhaktishree Nayak
Assistant Professor
Department of Mineral Engineering
Government College of Engineering, Keonjhar, Odisha

DISCLAIMER

Module-1

Mineral- Mineral is a naturally occurring crystalline substance having a definite but generally not fixed chemical composition.
Minerals may be ore forming mineral or rock forming mineral.e.g. hematite,galena,magnesite are ore forming minerals and quartz,calcite,feldspar are some of the ore forming mineral.

Ore- ore is the association of ore mineral and gangue mineral. Ore is a rock body that is enriched in one or more minerals of economic value.

Ore Mineral-It is the mineral from which metallic minerals can be extracted economically.
E.g. Hematite, pyrolusite

Gangue Mineral-It is the mineral associated with the ore mineral which is of no value but nevertheless have to be mined along with the ore mineral.
e.g. calcite, quartz

Rock-it is the association of various minerals.It may be igneous, sedimentary or metamorphic variety. e.g.granite,marble, sandstone etc…

Mineral deposit- aggregate of a mineral in an unusually high concentration. All ore deposits are mineral deposits, but the reverse is not true. Ore deposit is an economic term, while mineral deposit is a geologic term.

Ore genesis- ore genesis Process by which a mineral deposit forms. Metalliferous mineral deposits may be syngenetic (formed at the same time as the host rocks) or epigenetic (deposited later than the host rocks).

Classification of mineral deposits

There are mainly four types of mineral deposits on the basis of processes of formation-

1) Igneous process

1. Magmatic concentration
2. pegmatite injection
3. contact metasomatism
4. hydrothermal process

2) Sedimentary process

1. Residual and mechanical concentration
2. oxidation and supergene enrichment
3. Sublimation
4. evaporation

3) Metamorphic process-

1. metamorphism
2. metasomatism

Ore genesis processes at a glance

Magmatic process

Magmatic is when liquid magna cools and solidifies to form igneous rock, it forms ore of metals, gems and other precious resources.

Layered plutons

Magma of the mafic nature solidifies in layers. Every layer has different mineralization. Some layers may have rich deposits. There are three type of processes which produces layered plutons

- As magma solidifies (plutonic) its temperature gradually decreases. Minerals crystalize first in the liquid magma. Some crystals are denser than the magma which will settle down and is concentrated at the bottom which is also called crystal settling.
- In the mafic magma crystallization usually starts from the bottom so early forming minerals are concentrated at the base.
- When these processes occur and form minerals, at some time different magma can enter these mineraliztion which can change the early minerals formed.

Kimberlites

Kimberlites are igneous rocks that are produced in the mantle and are the main diamonds source.

Volcanic vent deposits

Volcanic vent deposits are from the gases escaping from the volcano where it precipitates such as sulphur. Sulphur usually deposits as a pure yellow deposition from the escaping gases and are used in sulphuric acid manufacturing.

Hydrothermal process

Hydrothermal process is the most common ore forming process. Water is heated by the magma chamber and this water dissolves metals. Metals are dissolved in the water and this solution seeps through cracks, fractures and through permeable rocks until they are precipitated and form a deposit. There are three types of water sources

- Magmas of granitic composition when solidifies leaves a water-rich residual fluid which precipitates and form ore body.
- In active volcanic activities when ground water seeps down through the crust, these magma chamber heats the water which provides the hydrothermal solution. This hydrothermal solution is at shallow depths and its precipitation makes an ore.
- Sea water is heated when it seeps along cracks in the oceanic crust mostly at the mid oceanic ridges and submarine volcanoes.

As of the fact that salty water increases the solubility of the water which is further enhanced by the heating. Hot salty water is a powerful agent in dissolving and transporting metals.Small amount of metal is present by an average in every crustal rocks so these hydrothermal solutions dissolves the tiny concentrates which percolating through permeable rock and cracks, ultimately in huge amount is precipitated to form an ore.
There are several types of hydrothermal mineralization

- Hydrothermal vein deposits are formed when these hydrothermal solutions enter a country rock along cracks and fractures. It precipitates in the parent rock in a vein like structure.
- The hydrothermal solution in vein deposits can also soak through the country rock which for disseminated ore deposits. This is less concentrated but as formed with the vein together they form economical deposit.
- Disseminated copper depoits are associated with porphyry copper deposits. This depoist is associated with granitic to dioritic composition.

Sedimentary process

- Sedimentary process includes sedimentary sorting and precipitation.
- Sedimentary sorting
- Sedimentary sorting is the settling down of heavy minerals first and later of the less denser particles. Example of such sorting is settling of gold in a stream when water slows down. As streams flows it carries clay, sand and gold particles. Gold settles down and conceive in the bedrock into coarser sediments. Gold concentrates in the bedrock and coarser gravel and is placer deposits.

Precipitation

Water seeping through the soil and bedrock dissolve ions which then flows into streams and oceans providing sodium and chloride ions which makes water salty. these can deposit only by the evaporation process which is not possible in the ocean however, lakes developed in the deserts evaporates and evaporites deposits are formed by precipitating crystals.

Weathering process

Environments of high rainfall, water dissolves most soluble ions forms the soil and exposed surface rocks where insoluble ions are left as a residual. Iron and aluminium have less solubility so these ions are left behind which forms the **bauxite**. Bauxite is the principal aluminium providing residual but in come cases iron can also accumulate enough to be economical deposit. Weathering process can also provide metals to ores which are produced by other processes. Disseminated deposits contain metals but are not economical to mine so ground water and rainfall weathers these metals. In some cases metals react to weathering instead of removal which creates a **supergene ore** rich in metals above low grade mineralization.

Metamorphic process

Metamorphic rocks form by heat and pressure altering mineralogy and it can also expel water from the rocks. This water due to heat makes hydrothermal deposits so they are also associated with metamorphism.

Ore genesis in detail

Magmatic concentration process

Magma is molten rock, together with any suspended mineral grains and dissolved gases, that forms when temperatures rise and melting occurs in the mantle or crust. When magma rises to Earth's surface through fissures and volcanic vents, it is called lava. Lava cools and crystallizes quickly, so that igneous rocks formed from lava tend to consist of tiny mineral grains. (Sometimes cooling can be so rapid that mineral grains cannot form and a glass results.) Underground magma, on the other hand, cools and crystallizes slowly, and the resulting igneous rocks tend to contain mineral grains at least one-half centimetre (about one-quarter inch) in diameter.

There are mainly two phases of magmatic concenytration process.

1. **Early magmatic phase**- seggregation, Dissemination and injection
2. **Late magmatic Phase**-Residual Liquid Seggregation, Residual Liquid injection, Immiscible Liquid Seggregation and Immiscible Liquid Injection

Early magmatic phase

Magmatic segregation is a general term referring to any process by which one or more minerals become locally concentrated (segregated) during the cooling and crystallization of a magma. Rocks formed as a result of magmatic segregation are called magmatic cumulates. While a magma may start as a homogeneous liquid, magmatic segregation during crystallization can produce an assemblage of cumulates with widely differing compositions. Extreme segregation can sometimes produce monomineralic cumulates; a dramatic example occurs in the Bushveld Igneous Complex of South Africa, where cumulus layers of chromite (iron-magnesium-chromium oxide, the only chromium ore mineral) are encased in cumulus layers of anorthite (calcium-rich feldspar). Mineral deposits that are magmatic cumulates are only found in mafic and ultramafic igneous rocks (i.e., rocks that are low in silica). This is due to the control exerted by silica on the viscosity of a magma: the higher the silica content, the more viscous a magma and the more slowly segregation can proceed. Highly viscous magmas, such as those of granitic composition, tend to cool and crystallize faster than segregation can proceed. In low-silica (and, hence, low-viscosity) magmas such as gabbro, basalt, and komatiite, mineral grains can float, sink, or be moved so rapidly by flowing magma that segregation can occur before crystallization is complete.

As with most geologic processes that cannot be directly observed, a certain amount of uncertainty exists about how cumulates form. A mineral such as chromite, with a density considerably greater than the magma from which it crystallizes, will tend to sink as soon as it forms. As a result, geologists long held the opinion that cumulates of chromite and other dense minerals formed only by sinking. This simple picture was challenged in 1961 by E. Dale Jackson, a geologist employed by the U.S. Geological Survey, who studied chromite cumulates of the Stillwater Complex in Montana. The findings of Jackson and later workers suggested that cumulates can also be produced by such phenomena as in-place crystallization of monomineralic layers on the floor of a magma chamber or density currents carrying mineral grains from the walls and roof of a magma chamber to the floor. Opinion still remains open, but most geologists now agree that in-place crystallization and density currents are more important in the formation of magmatic cumulates than density sinking.

Three oxide ore minerals form magmatic cumulates: chromite, magnetite, and ilmenite. The world's largest chromite deposits are all magmatic cumulates; the largest and richest of these is in the Bushveld Complex of South Africa. Cumulus deposits of magnetite make poor iron ores, because cumulus magnetites invariably contain elements such as titanium, manganese, and vanadium by atomic substitution—although vanadiferous magnetites are important as a source of vanadium. In fact, much of the world's production of this metal comes from cumulus magnetites in the Bushveld Complex.

Late magmatic phase

A different kind of magmatic segregation involves liquid immiscibility. A cooling magma will sometimes precipitate droplets of a second magma that has an entirely different composition. Like oil and water, the two magmas will not mix (i.e., they are immiscible). The chemical principle governing precipitation of an immiscible liquid is the same as that governing crystallization of a mineral from a magma: when the concentration of a particular mineral within a parent magma reaches saturation, precipitation occurs. If saturation is reached at a temperature above the melting point of the mineral, a drop of liquid precipitates instead of a mineral grain. The composition of this immiscible drop is not exactly that of the pure mineral, because the liquid tends to scavenge and concentrate many elements from the parent magma, and this process can lead to rich ore deposits.

Iron sulfide is the principal constituent of most immiscible magmas, and the metals scavenged by iron sulfide liquid are copper, nickel, and the platinum group. Immiscible sulfide drops can become segregated and form immiscible magma layers in a magma chamber in the same way that cumulus layers form; then, when layers of sulfide magma cool and crystallize, the result is a deposit of ore minerals of copper, nickel, and platinum-group metals in a gangue of an iron sulfide mineral. Among the ore deposits of the world formed in this way are the Merensky Reef of the Bushveld Complex, producer of a major fraction of the world's platinum-group metals; the Stillwater Complex, Montana, host to platinum-group deposits similar to the Merensky Reef; and the Norilsk deposits of Russia, containing large reserves of platinum-group metals.

Under suitable conditions, immiscible sulfide liquids can also become segregated from flowing lavas. An example is offered by the Kambalda nickel deposit in Western Australia. At Kambalda a nickel ore mineral, pentlandite, together with valuable by-product minerals of copper and platinum-group metals, crystallized in an iron-sulfide-rich gangue from a sulfide liquid that had become segregated from a magnesium-rich lava called a komatiite (named for the Komati River in South Africa). A group of unique deposits formed by immiscible sulfide liquids is the Sudbury Igneous Complex in Ontario, Canada, which formed about 1.85 billion years ago. Elliptical in outline (approximately 60 kilometres long by 28 kilometres wide), the complex has the shape of a funnel pointing down into the Earth. A continuous lower zone of a mafic rock called norite lies above a discontinuous zone of gabbro, some of which contains numerous broken fragments of the underlying basement rocks and some of which is rich in sulfide ore minerals of nickel, copper, and platinum-group metals. Many hypotheses have been suggested for the origin of the Sudbury Complex. Some consider it to be an intrusive igneous complex, and some consider it a combination of intrusive and extrusive igneous rocks, but the most widely held opinion derives from the work of the American scientist Robert S. Dietz, who in 1964 suggested that the Sudbury structure is an astrobleme, the site of a large meteorite impact. The complex's sulfide ore bodies are thought to be derived from immiscible magmas formed in Earth's mantle as a result of the impact (and possibly mixed with meteorite material), while the uppermost layers are thought to be rock debris remaining from the impact.

A different form of segregation results from liquid immiscibility. In exactly the same way that oil and water will not mix but form immiscible globules of one within the other, so in a mixed sulfide-silicate magma the two liquids will tend to segregate. Sulfide droplets separate out and coalesce to form globules which, being denser than the silicate rich magma, sink through it to accumulate at the base of the intrusion or lava flow (Fig, 4.1, Page 54, Evans). Iron sulfide is the principal constituent of these droplets, which are associated with basic and ultrabasic rocks because sulfur and iron are both more abundant in these rocks than in acid or intermediate plutonic rocks. Chalcophile elements, such as copper and nickel also enter these droplets and sometimes the platinum group metals also partition into the sulfide droplets (Groves et al. 19896). A basic or ultrabasic magma is generated by partial melting in the mantle and it may acquire its sulfur at this time, or later by assimilation in the crust. For significant sulfide generation to occur the magma must be sulfide saturated. If immiscible sulfides form, equilibrate with the silicate magma settle and accumulate on the substrate in a single stage, after which the magma begins to crystallize olivine, then we have the process known as batch equilibrium. If the proportion of sulfide formed is large, much of the available Ni in the magma is removed, and if the ratio of mass of magma to mass of sulfide is about 1000 or below, then there will be obvious Ni depletion in the magma and the consolidated silicate 5 5 rocks will carry a geochemical mark that can be used both to identify favourable exploration targets and give indication of the tenor of Ni in the possible associated mineralization. Contrasting with batch equilibrium we may have fractional segregation. This is a more continual process in which small amounts of sulfide become immiscible and then settle. The silicate melt is still sulfide saturated and crystallization of just a small amount of olivine will increase the sulfide concentration in the remaining liquid, thereby forcing some more dissolved sulfide out of solution. For the formation of an ore deposit the timing of the liquation is critical (Naldrelt et al. 1984). If it is too early then the sulfides may settle out in the mantle or the lower curst; if it is too late then crystallization of silicates may be in full swing and they will dilute any sulfide accumulations. The process that can promote sulfide immiscibility are; cooling, silication (increase of silica content by assimilation), sulfur assimilation and magma mixing. The accumulation of Fe-Ni-Cu sulfide droplets beneath the silicate fraction can produce massive sulfide ores. These are overlain by a zone with subordinate silicates enclosed in a net work of sulfides net-textured ore, sometimes called disseminated ore. This zone is in turn, overlain by one of weak mineralization which grades up into overlying peridotite, gabbro or komatiite, depending on the nature of the associated silicate fraction. (Fig. 11.3 Page 146, Evans) shows layering of Cu-Ni ores in komatiite flow or sill. Orthomagmatic titanium deposits in anorthosites are also considered to be of liquation on origin.

Pegmatitic injection

The crystallization of magma is a complex process because magma is a complex substance. Certain magmas, such as those which form granites, contain several percent water dissolved in them. When a granitic magma cools, the first minerals to crystallize tend to be anhydrous (e.g., feldspar), so an increasingly water-rich residue remains. Certain rare chemical elements, such as lithium, beryllium, and niobium, that do not readily enter into atomic substitution in the main granite minerals (feldspar, quartz, and mica) become concentrated in the water-rich residual magma. If the crystallization process occurs at a depth of about five kilometres or greater, the water-rich residual magma may migrate and form small bodies of igneous rock, satellitic to the main granitic mass, that are enriched in rare elements. Such small igneous bodies, called rare-metal pegmatites, are sometimes exceedingly coarse-grained, with individual grains of mica, feldspar, and beryl up to one metre across. Pegmatites have been discovered on all continents, providing an important fraction of the world's lithium, beryllium, cesium, niobium, and tantalum. Pegmatites also are the major source of sheet mica and important sources of gemstones, particularly tourmalines and the gem forms of beryl (aquamarine and emerald).

Hydrothermal Process

Hydrothermal mineral deposits are those in which hot water serves as a concentrating, transporting, and depositing agent. They are the most numerous of all classes of deposit. Hydrothermal deposits are never formed from pure water, because pure water is a poor solvent of most ore minerals. Rather, they are formed by hot brines, making it more appropriate to refer to them as products of hydrothermal solutions. Brines, and especially sodium-calcium chloride brines, are effective solvents of many sulfide and oxide ore minerals, and they are even capable of dissolving and transporting native metals such as gold and silver.

The water in a hydrothermal solution can come from any of several sources. It may be released by a crystallizing magma; it can be expelled from a mass of rock undergoing metamorphism; or it may originate at Earth's surface as rainwater or seawater and then trickle down to great depths through fractures and porous rocks, where it will be heated, react with adjacent rocks, and become a hydrothermal solution. Regardless of the origin and initial composition of the water, the final compositions of all hydrothermal solutions tend to converge, owing to reactions between solutions and the rocks they encounter.

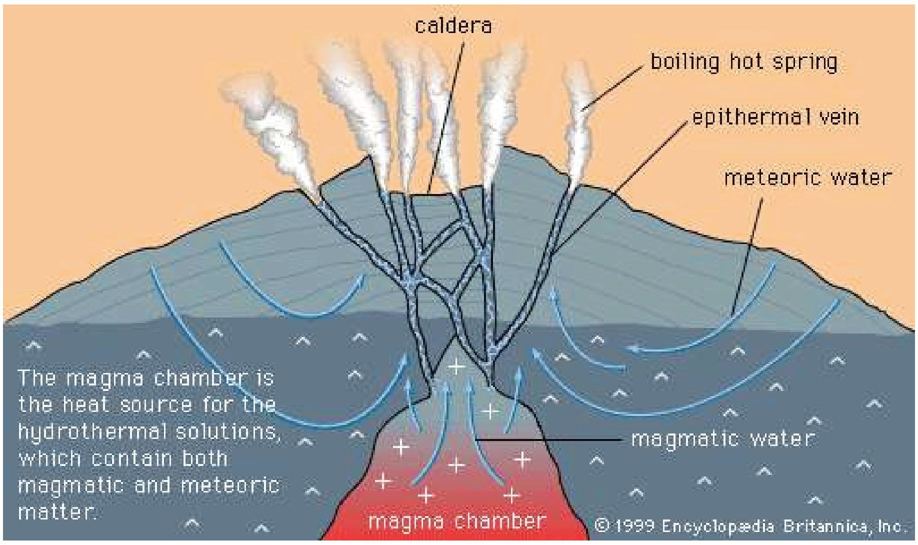
Hydrothermal solutions are sodium-calcium chloride brines with additions of magnesium and potassium salts, plus small amounts of many other chemical elements. The solutions range in concentration from a few percent to as much as 50 percent dissolved solids by weight. Existing hydrothermal solutions can be studied at hot springs, in subsurface brine reservoirs such as those in the Imperial Valley of California, the Cheleken Peninsula on the eastern edge of the Caspian Sea in Turkmenistan, in oil-field brines, and in submarine springs along the mid-ocean ridge. Fossil hydrothermal solutions can be studied in fluid inclusions, which are tiny samples of solution trapped in crystal imperfections by a growing mineral.

Because hydrothermal solutions form as a result of many processes, they are quite common within Earth's crust. Hydrothermal mineral deposits, on the other hand, are neither common nor very large compared to other geologic features. It is apparent from this that most solutions eventually mix in with the rest of the hydrosphere and leave few obvious traces of their former presence. Those solutions that do form mineral deposits (and thereby leave obvious evidence of their former presence) do so because some process causes them to deposit their dissolved loads in a restricted space or small volume of porous rock. It is most convenient, therefore, to discuss hydrothermal mineral deposits in the context of their settings.

Veins

The simplest hydrothermal deposit to visualize is a vein, which forms when a hydrothermal solution flows through an open fissure and deposits its dissolved load. A great many veins occur close to bodies of intrusive igneous rocks because the igneous rocks serve as heat sources that create convectively driven flows in hydrothermal solutions. Precipitation of the minerals is usually caused by cooling of the hydrothermal solution, by boiling, or by chemical reactions between the solution and rocks lining the fissure. Some famous deposits are the tin-copper-lead-zinc veins of Cornwall, England; the gold-quartz veins of Kalgoorlie, Western Australia, Australia, and Kirkland Lake, Ontario, Canada; the tin-silver veins of Llallagua and Potosí, Bolivia; and the silver-nickel-uranium veins of the Erzgebirge, Germany, which were first described by Georgius Agricola in his book *De re metallica* (1556).

Hydrothermal deposits formed at shallow depths below a boiling hot spring system are commonly referred to as *epithermal*, a term retained from an old system of classifying hydrothermal deposits based on the presumed temperature and depth of deposition. Epithermal veins tend not to have great vertical continuity, but many are exceedingly rich and deserving of the term *bonanza*. Many of the famous silver and gold deposits of the western United States, such as Comstock in Nevada and Cripple Creek in Colorado, are epithermal bonanzas.



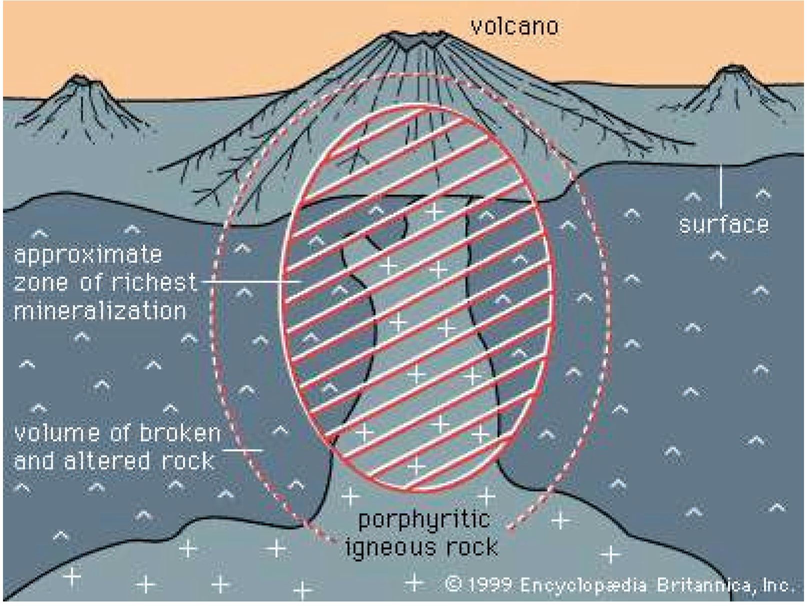
The relationship between hot springs and epithermal veins.*Encyclopædia Britannica, Inc.*

Porphyry deposits

Among the most distinctive hydrothermal deposits is a class known as porphyry copper deposits, so called because they are invariably associated with igneous intrusives that are porphyritic (meaning the rock is a mixture of coarse and fine mineral grains). Porphyry copper deposits (and their close relatives, porphyry molybdenum deposits) contain disseminated mineralization, meaning that a large volume of shattered rock contains a ramifying network of tiny quartz veins, spaced only a few centimetres apart, in which grains of the copper ore minerals chalcopyrite and bornite (or the molybdenum ore mineral molybdenite) occur with pyrite. The shattered rock serves as a permeable medium for the circulation of a hydrothermal solution, and the volume of rock that is altered and mineralized by the solution can be huge: porphyry coppers are among the largest of all hydrothermal deposits, with some giant deposits containing many billions of tons of ore. Although in most deposits the ore averages only between 0.5 and 1.5 percent copper by weight, the tonnages of ore mined are so large that more than 50 percent of all copper produced comes from porphyry coppers.

porphyryPorphyry.*Encyclopædia Britannica, Inc.*

Porphyry coppers are often associated with stratovolcanoes. As a result of the volcanism that rings the Pacific Ocean basin, porphyry coppers are conspicuous features of mineralization along the western borders of North and South America and in the Philippines. Among the major deposits are El Teniente, El Salvador, and Chuquicamata in Chile, Cananea in Mexico, and, in the United States, Bingham Canyon in Utah, Ely and Yerington in Nevada, and San Manuel in Arizona.



Idealized drawing of a porphyry copper deposit, showing the relationship between the porphyry body, the altered and mineralized rock, and the overlying volcano.*Encyclopædia Britannica, Inc.*

Skarns

When a limestone or marble is invaded by a high-temperature hydrothermal solution, the carbonate minerals calcite and dolomite react strongly with the slightly acid solution to form a class of mineral deposit called a skarn. Because solutions tend to have high temperatures close to a magma chamber, most skarns are found immediately adjacent to intrusive igneous rocks. The solutions introduce silica and iron, which combine with the calcium and magnesium in the parent rock to form silicate minerals such as diopside, tremolite, and andradite. The hydrothermal solutions may also deposit ore minerals of iron, copper, zinc, tungsten, or molybdenum.

The mining of magnetite from a skarn deposit at Cornwall, Pennsylvania, U.S., commenced in 1737 and continued for two and a half centuries. Copper skarns are found at many places, including Copper Canyon in Nevada and Mines Gaspé in Quebec, Canada. Tungsten skarns supply much of the world's tungsten from deposits such as those at Sangdong, Korea; King Island, Tasmania, Australia; and Pine Creek, California, U.S.

Volcanogenic massive sulfides

Wherever volcanism occurs beneath the sea, the potential exists for seawater to penetrate the volcanic rocks, become heated by a magma chamber, and react with the enclosing rocks—in the process concentrating geochemically scarce metals and so forming a hydrothermal solution. When such a solution forms a hot spring on the seafloor, it can suddenly cool and rapidly deposit its dissolved load. Mineral deposits formed by this process, which are called volcanogenic massive sulfide (VMS) deposits, are known in ancient seafloor rocks of all geologic ages. In addition, deposits forming today as a result of submarine hot-spring activity have been discovered at a number of places along the oceanic ridge (the most volcanically active zone on Earth), and in back-arc basins associated with subduction zones.

VMS deposits constitute some of the richest deposits of copper, lead, and zinc known. Some of the most famous, found in Japan and called *kuroko* deposits, yield ores that contain as much as 20 percent combined copper, lead, and zinc by weight, plus important amounts of gold and silver. Other famous VMS deposits are the historic copper deposits of Cyprus and, in Canada, the Kidd Creek deposit in Ontario and the Noranda deposits of Quebec.

Residual and mechanical concentration process

Weathering not only disintegrates a rock but by removing the undesirable constituents in it, concentrates the residual useful substance which forms an economic deposit.

The effects of weathering usually do not extend deeper than a couple of meters but occasionally reach 30 to 60 meters. It is most active in tropical and sub-tropical climates. In such climates, rock decay is carried further; leaching is more complete; the silicates are thoroughly broken down and surface water readily removes the silica, thus bringing about the concentration of the residual material which, when useful, forms valuable mineral deposits.

Bauxite is an important example of this kind. Valuable deposits of clay have been formed by removal in solution of the lime in a limestone bed. The removing by weathering of the useless constituents has brought about the concentration of the sparse nickel content in ultra-basic rocks to form valuable deposits of the metal.

Alluvial and eluvial deposits are the results of weathering and mechanical concentration. The tough, chemically stable useful metals or minerals disseminated through a rock are freed from their matrix and moving water or air progressively concentrate the released particles due to their higher specific gravity. In other words, nature acts as a gravity separator in which the heavy minerals are separated from the lighter ones. The only difference is that nature takes a much longer time to do the job.

- Under the action of weathering, rocks and enclosed mineral deposits undergo disintegration and decomposition - soluble parts are removed and insoluble residues accumulate, forming residual mineral deposits.
- Mechanical disintegration, such as that by frost action, frees minerals and renders them capable of being carried by various agencies, and be sorted according to size and specific gravity.

Residual Concentration:

- Residual concentration results in the accumulation of valuable minerals when undesired constituents of rocks or mineral deposits are removed during weathering.
- The concentration is largely due to a decrease in volume effected by surficial chemical weathering.
- The residues may continue to accumulate till their purity and volume make them of commercial importance.

Mechanical Concentration:

- Mechanical concentration is the natural gravity separation of heavy from light minerals by means of moving water or wind.
- The resulting deposits are called placer deposits and their formation involves two stages:

1) freeing of the stable minerals from their matrix by weathering, and
2) their concentration.

- Concentration can occur only if the valuable minerals have:
  a) high specific gravity
  b) chemical resistance to weathering, and
  c) durability (malleability, toughness and hardness).

Process of Formation of Residual Deposits:

- The first condition is the availability of rocks or lodes containing valuable minerals, of which the undesired substances are soluble and the desired ones insoluble under surface conditions.
- The climatic conditions should favour chemical decay. Tropical & sub-tropical climatic conditions are most favourable.
- The relief must not be too great, or the valuable minerals will be washed away as soon as they are in the least concentrated.
- Long continued crustal stability is essential for residues to accumulate in quantity, and the deposits may not be destroyed by erosion.
- Important deposits include: Iron ores, manganese, bauxite, clays, nickel, phosphate, kyanite, barite, ochers, tin, gold, etc.
- Given these conditions, a limestone formation with minor iron oxides will slowly be dissolved leaving the insoluble iron oxides as a residue. As bed after bed of limestone disappears, an overlying mantle of iron ores of sufficient thickness, and grade accumulates to make a workable deposit.

Residual deposits therefore form in two ways:

1) the residue is simply an accumulation of a mineral that has not changed during the process e.g. iron oxides in banded iron formations, and
2) the valuable mineral first comes into existence as a result of weathering processes, and then persists and accumulates e.g. the feldspars of a syenite decomposes upon weathering to form bauxite, which persists at the surface while other constituents are removed in solution.

- Valuable deposits of iron ore, manganese, bauxite, clays, nickel, phosphate, kyanite, barite, ochre, tin, gold and other substances occur as residual concentrations.

Residual Deposits and their Source Materials:

Iron Concentrations:

1) Lode deposits of siderite or iron sulfides - these residues are rarely used as iron ores.
2) Disseminated iron minerals in non-aluminous limestones.
3) Limestones that have been partly replaced by iron minerals, either before or during the period of weathering.
4) Basic igneous rocks.
5) ferruginous siliceous sediments.

Manganese Concentrations:

1) Limestones or dolomites low in alumina but containing disseminated syngenetic manganese carbonates and oxides.
2) Limestones containing disseminated introduced manganese. Carbonate rocks precipitate manganese under certain conditions.
3) Manganiferous silicate rocks such as crystalline schists or altered igneous rocks.

4) Lode deposits of manganese minerals or ores high in manganese e.g. veins, replacement deposits or contact metasomatic deposits (containing rhodochrosite, rhodonite, manganiferous siderite and calcite, spessartite, tephroite, alleghenite, piedmontite, hausmannite, manganosite, etc.).

Bauxite Formation:
Rocks relatively high in aluminum silicates and low in iron and free quartz e.g.
1) nephline syenite.
2) Limestones or clays in limestones
3) Clastic sediments derived from Archaean rocks
4) Basalts
5) Clay alluvium
6) Feldspathic sandstones

Clay Formation:
The source rocks are crystalline rocks and silicic granular rocks rich in feldspars and low in iron minerals such as:
1) Granites and gneisses
2) Basic ignous rocks
3) Feldspar rich pegmatites
4) Syenites
5) Limestones
6) Shales
7) Sericitized igneous rocks

Process of Formation by Mechanical Concentration:

When mineral grains of different density are moved by flowing water, the less dense grains will be most rapidly moved, and a separation of high-density and low-density grains can be effected. Mineral deposits formed as a result of gravity separation based on density are called *placer deposits*.

For effective concentration, placer minerals must not only have a high density (greater than about 3.3 grams per cubic centimetre), they must also possess a high degree of chemical resistance to dissolution or reaction with surface water and be mechanically durable. The common sulfide ore minerals do not form placers, because they rapidly oxidize and break down. Ore minerals having suitable properties for forming placers are the oxides cassiterite (tin), chromite (chromium), columbite (niobium), ilmenite and rutile (titanium), magnetite (iron), monazite and xenotime (rare-earth metals), and zircon (zirconium). In addition, native gold and platinum have been mined from placers, and several gemstone minerals--in particular, diamond, ruby, and sapphire--also concentrate in placers.

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The placers formed on the site of the destruction of the primary sources are known as *Eluvial*. When the weathered and disintegrated material is shifted downhill *Scree* or *Deluvial (talus)* placers are formed. Accumulation of the material at the foot of a slope can lead to the development of a *Proluvial (colluvial)* placer. When clastic and weathered material is carried away by streams, it serves as the source of *Stream (River*) or *Alluvial* placers. *Beach* or *Lateral* placers are built up along the shores of lakes, seas and oceans. In addition, *Glacial* placers can develop as a result of glacial activity and Eolian placers as a result of the action of wind.

- Placer minerals that can be mechanically concentrated are gold, platinum, tin-stone, magnetite, chromite, ilmenite, rutile, native copper, gemstones, zircon, monazite, phosphate and quicksilver (rare).
- Depending upon the agency involved, placers are of three types:
    1) Eluvial placers - form upon hill slopes, concentration of valuable minerals by gravity
    2) Stream or alluvial placers - concentration of valuable minerals by running water
    3) Eolian placers - concentration of valuable minerals by wind action

Eluvial Palcers:

These may be considered an intermediate or embryonic stage in the formation of stream or beach placers. They are formed, without stream action, upon hill slopes from materials released from weathered lodes that outcrop above them. The heavier, resistant minerals collect below the outcrops; the lighter nonresistant products of decay are dissolved or swept downhill by train wash or are blown away by wind. This brings about a partial concentration by reduction in volume, a process that continues with continued down slope creed. Fairly rich lodes necessary to yield workable deposits by this incomplete concentration. Important deposits formed in this manner are of gold and tin, minor deposits include manganese, tungsten, kyanite, barite and gemstones.

Stream or Alluvial Placers:

Flowing water is the most effective separator of heavy from light material, and stream placers are the most important type of placid deposits. They have even the greatest quantity of placid gold, in stone, Platinum, and precious stones. Likely places of accumulation of heavy material along a stream channel are:

i. the middle reaches of streams
ii. where streams flow through polished canyon floors
iii. where they enter valleys of gentler gradient
iv. convex side of meanders
v. where streams cross highly inclined or vertically layered hard and soft rocks
vi. at the confluence of two streams, at the mouth of the more sluggish one

The minerals that make up placer deposits may be derived from:

a) Commercial deposits, such as gold veins, and
b) Non-commercial lodes such as gold stringers or veinlets of cassiterite.

Eolian Placers:

Wind instead of water may act as the agent of concentration and give rise to placer deposits. This can occur only in arid regions. These are the least important of all placer deposits. It is reported that some eolian gold placers have been formed in the Australian deserts from the disintegration of gold quartz lodes. The light decomposed materials have been blown away; the heavy gold particles, freed from their matrix, remained behind. Similar concentration has taken place El Arco, in Lower California, Mexico.

Oxidation and supergene enrichment process

When ore deposits are exposed to the oxidation zone they are weathered and altered with the country rocks. The surface waters oxidize many ore minerals and yield solvents that dissolve other minerals.An orebody thus becomes oxidized and generally leached of many of its valuable materials down to the groundwater table, or to depth where oxidation cannot take place.The effects oxidation may, however, extend far below the one of oxidation. As the cold, dilute, leaching solutions trickle downwards, they may lose a part or all of their metallic content within the zone of oxidation to give rise to oxidized ore deposits. The oxidized or near-surface part of an orebody is made colorful due to the oxidation of sulfides to oxides and sulfates.As the down trickling solutions penetrate the water table, their metallic content may be precipitated in the form of secondary sulfides to give rise to a zone of secondary or supergene sulfide enrichment. The lower, unaffected part of the orebody is called the hypogene zone. In some places the supergene zone is absent and in rare cases the oxidized zone may be shallow or lacking (as in some glaciated areas undergoing rapid erosion). Special conditions of time, climate, physiographic development and amenable ores are necessary for the process of oxidation and supergene enrichment to be effective. Such ores occur in most of the non-glaciated land areas of the world.

Secondary enrichment

An especially important class of residual deposit is formed by both the removal of valueless material in solution and the solution and redeposition of valuable ore minerals. Because solution and redeposition can produce highly enriched deposits, the process is known as a secondary enrichment.

Secondary enrichment can affect most classes of ore deposit, but it is notably important in three circumstances:

1. The first circumstance arises when gold-bearing rocks--even rocks containing only traces of gold--are subjected to lateritic weathering. Under such circumstances, the gold can be secondarily enriched into nuggets near the base of the laterite. The importance of secondary enrichment of gold in lateritic regions was realized only during the gold boom of the 1980s, especially in Australia.
2. The second circumstance involves mineral deposits containing sulfide minerals, especially copper sulfides, that are subjected to weathering under desert conditions. Sulfide minerals are oxidized at the surface and produce sulfuric acid, and acidified rainwater then carries the copper, as copper sulfate, down to the water table. Below the water table, where sulfide minerals remain unoxidized, any iron sulfide grains present will react with the copper sulfate solution, putting iron into solution and precipitating a copper mineral. The net result is that copper is transferred from the oxidizing upper portion of the deposit to that portion at and just below the water table. Secondary enrichment of porphyry copper deposits in the southwestern United States, Mexico, Peru, and Chile is an important factor in making those deposits ores. Lead, zinc, and silver deposits are also subject to secondary enrichment under conditions of desert weathering.
3. The third circumstance in which secondary enrichment is important involves Banded Iron Formations and sedimentary manganese deposits. A primary BIF may contain only 25 to 30 percent iron by weight, but, when subjected to intense weathering and secondary enrichment, portions of the deposit can be enriched to as high as 65 percent iron. Some primary BIFs are now mined and beneficiated under the name taconite, but in essentially all of these deposits mining actually commenced in the high-grade secondary-enrichment

zone. Sedimentary manganese deposits, especially those formed as a result of submarine volcanism, must also be secondarily enriched before they become ores.

Effects of Oxidation & Supergene Enrichment:

- Effects of oxidation on mineral deposits are profound - the minerals are altered and the structure is obliterated.
- The metallic substances are leached or altered to new compounds which require different metallurgical treatment for their extraction unlike that employed for the extraction for the unoxidized ore.
- The texture and type of deposits are obscured. Compact ores are rendered cavernous, ubiquitous limonite obscures everything and imparts to the gossan the familiar rusty color. The effects are therefore:

1) To render barren the upper parts of many ore deposits.
2) To change minerals into more usable or less usable form or to make rich bonanzas.
3) Supergene enrichment may add much where there was little.
4) Leaner parts of the vein may be made rich.
5) Unworkable protore may be enriched to the ore grade. E.g. many of the copper districts would not have come into existence except for the process of enrichment.

- Water with dissolved and entangled oxygen is the most powerful oxidizing agent, but carbon dioxide also plays n important role.
- Locally chlorides, bromides and iodides also play an important role.
- These substances react with certain minerals to yield strong solvents, such as ferric sulfate and sulfuric acid.
- Sulfuric acid, in turn, reacting with sodium chloride yields hydrochloric acid, with which iron yields the strongly oxidizing ferric chloride.
- Bacteria also promote oxidation, they oxidize ferrous iron to ferric iron at low pH.

Oxidation & Solution in the Zone of Oxidation:

- Supergene oxidation and reduction enrichment go hand in hand. Without oxidation there can be no supply of solvents from which minerals may later be precipitated in the two zones.
- The process operates in three stages:

1) Oxidation & solution in the zone of oxidation
2) Deposition in the zone of oxidation
3) Supergene sulfide deposition

Chemical Changes:

- There are two main chemical changes within the zone of oxidation:
    a) Oxidation, solution and removal of the valuable material.
    b) Transformation, in situ, of metallic minerals into oxidized compounds.

- Most metallic minerals contain pyrite, which rapidly yields sulfur to form iron sulfate and sulfuric acid:

$$FeS_2 + 7O + H_2O \rightarrow FeSO_4 + H_2SO_4$$

$$2FeSO_4 + H_2SO_4 + O \rightarrow Fe_2(SO_4)_3 + H_2O$$

- The ferrous sulfate readily oxidizes to ferric sulfate and ferric hydroxide:

$$6FeSO_4 + 3O + 3H_2O \rightarrow Fe_2(SO_4)_3 + 2Fe(OH)_3$$

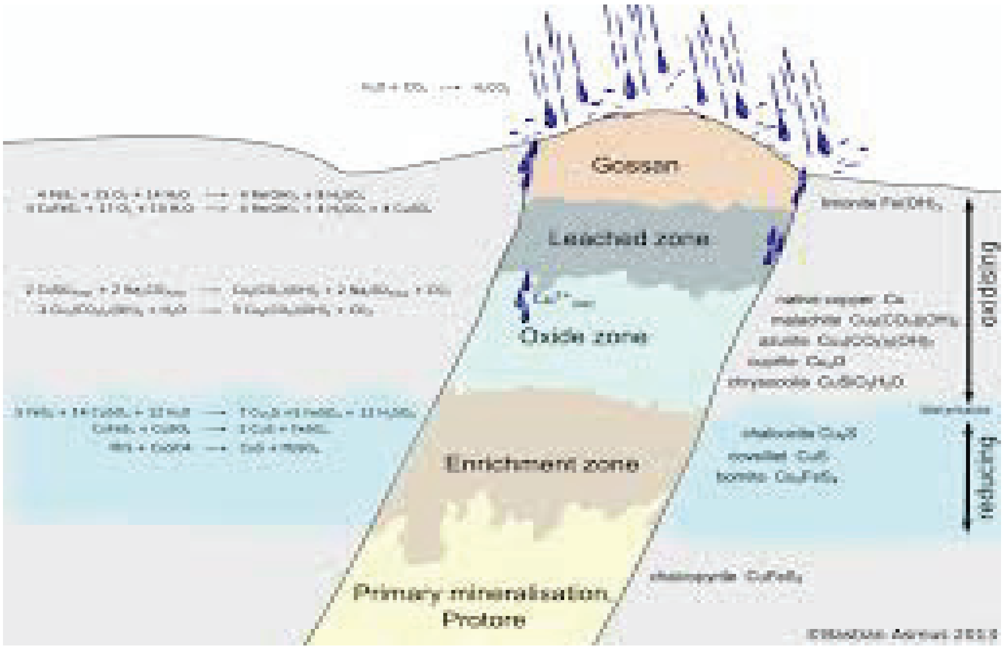
- The ferric sulfate hydrolizes to ferric hydroxide and sulfuric acid:
  $Fe_2(SO_4)_3 + 6H2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4$

- Ferric sulfate is also a strong oxidizing agent and attacks pyrite and other sulfides to yield more ferrous sulfate:
  $Fe_2(SO_4)_3 + FeS_2 \rightarrow 3FeSO_4 + 2S$

- The ferric hydroxide changes over to hematite and goethite and forms the ever present "limonite" that characterizes all oxidized zones;
- The part played by ferric sulfate as a solvent can be seen by the following reactions:

Pyrite	$FeS_2 + Fe_2(SO_4)_3 \rightarrow 3FeSO_4 + 2S$
Chalcopyrite	$CuFeS_2 + 2Fe_2(SO_4)_3 \rightarrow CuSO_4 + 5FeSO_4 + 2S$
Chalcocite	$Cu_2S + Fe_2(SO_4)_3 \rightarrow CuSO_4 + 2FeSO_4 + CuS$
Covellite	$CuS + Fe_2(SO_4)_3 \rightarrow 2FeSO_4 + S$
Sphalerite	$ZnS + 4Fe_2(SO_4)_3 + H_2O \rightarrow ZnSO_4 + 8FeSO_4 + 4H_2SO_4$
Galena	$PbS + Fe_2(SO_4)_3 + H_2O + 3O \rightarrow PbSO_4 + 2FeSO_4 + H_2SO_4$
Silver	$2Ag + Fe_2(SO_4)_3 \rightarrow Ag_2SO_4 + 2FeSO_4$

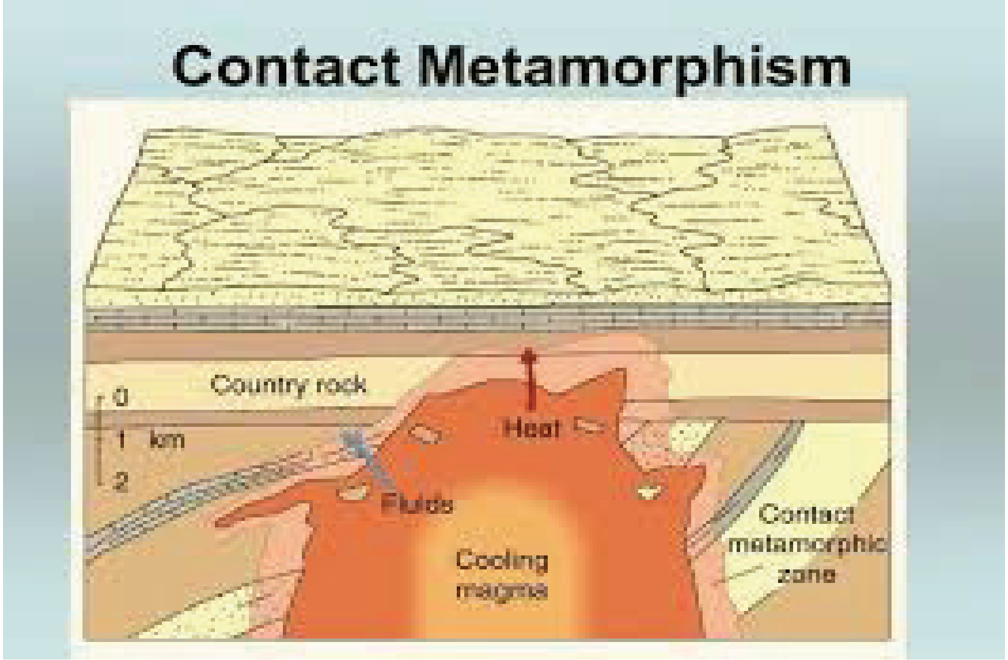
Most of the sulfates formed are readily soluble, and these cold dilute solutions slowly trickle downwards through the deposit till the proper Eh-pH conditions are met to cause deposition of their metallic content. If pyrite is absent in deposits undergoing oxidation, only minor mounts of solvents are formed, and the effects are mild. This is illustrated in the New Cornelia Mine, Ajo, Arizona. A country rock of limestone tends to inhibit migration of some sulfate solutions.



Contact metasomatismc process

Metasomatic replacement, the process of simultaneous solution and deposition whereby one mineral replaces another. It is an important process in the formation of epigenetic mineral deposits (those formed after the formation of the host rock), in the formation of high- and intermediate-temperature hydrothermal ore deposits, and in supergene sulfide enrichment (enriched by generally downward movement). Metasomatic replacement is the method whereby wood petrifies (silica replaces the wood fibres), one mineral forms a pseudomorph of another, or an ore body takes the place of an equal volume of rock. Replacement occurs when a mineralizing solution encounters minerals unstable in its presence. The original mineral is dissolved and almost simultaneously exchanged for another. The exchange does not occur molecule for molecule, but volume for volume; hence, fewer molecules of a less dense mineral will replace those of a more dense mineral. Replacement takes place first along major channels in a host rock through which the hydrothermal solutions flow. Smaller openings, even those of capillary size, eventually are altered, the smallest by diffusion at the very front of the exchange where solutions cannot flow.

Early-formed replacement minerals are themselves replaced, and definite mineral successions have been established. The usual sequence among the commoner hypogene (deposited by generally ascending solutions) metallic sulfide minerals is pyrite, enargite, tetrahedrite, sphalerite, chalcopyrite, bornite, galena, and pyrargyrite. Although replacement can occur at any temperature or pressure, it is most effective at elevated temperatures, at which chemical activity is enhanced. Replacement by cold circulating waters mostly is confined to soluble rocks, such as limestone. These may be replaced by iron oxides, manganese oxides, or calcium phosphates; vast surface deposits of copper and zinc carbonates have also formed where limestones were replaced, and valuable deposits have occurred where supergene sulfide enrichment occurs. With higher temperatures, replacement increases until, at high temperatures, hardly any rock may resist. Solutions at intermediate temperatures form simple sulfides and sulfosalts for the most part, and those at higher temperatures form sulfides and oxides. Replacement deposits are the largest and most valuable of all metallic ore deposits except those of iron.



Metamorphic Process of Ore genesis

Metamorphic processes profoundly alter pre-existing mineral deposits and form new ones. The chief agencies involved are heat, pressure, time, and various solutions. The materials acted upon are either earlier formed mineral deposits or rocks. Valuable nonmetallic mineral deposits are formed from rocks chiefly by the crystallization and the combination of rock making minerals.

Role of Temperature and Pressure

Metamorphic processes occur to make adjustments between the chemical potential of any system and the changes in temperature and pressure. A particular chemical reaction that cannot occur in one environment may readily do so under different temperature and pressure conditions.

An increase in pressure will cause a reaction to move in a direction in which the total volume of the system decreases, for example increasing pressure results in the following changes with a reduction in the total molar volume:

Olivine + anorthite → garnet
augite +anorthite → garnet + quartz
ilmenite + anorthite → sphene + hornblende
nephelene + albite → glaucophane or jadeite
anorthite + gehlenite + wollastonite → grossularite
andalusite → sillimanite → kyanite

An increase in temperature normally results in endothermic reactions. A possible example is the conversion of pyroxene to hornblende during the metamorphism of diabase to amphibolites. In short, metamorphic reactions result from the tendency of mineral systems to adjust to their physicochemical environment of high temperatures and pressures in contrast to the low temperatures of weathering processes, both of which processes generally occur in the presence of water.

Metamorphism of Earlier Deposits

When rocks are metamorphosed, enclosed mineral deposits may also be metamorphosed. Unlike rocks that undergo both textual and mineralogical changes, Ores undergo less mineral re-combinations. Textual changes, however, are pronounced. Schistose or gneissic textures are induced, particularly with sectile minerals, and flow structure is not uncommon. Galena, for example, becomes gneissic. It may also be rendered so fine grained that individual cleavage surfaces cannot be discerned with a hand lens. It "flows" around hard minerals, such as pyrite. Other minerals, such as chalcopyrite, bornite, covellite, or stibnite, behave similarly. The result is that ores may exhibit streaked, banded, smeared appearances with indistinct boundaries between minerals of different color. The original textures and structures may be so obscured that it is difficult to determine to which class the originally deposits belonged. Such deposits are then classified as "metamorphosed".

Formation of Mineral Deposits by Metamorphism

Several kinds of nonmetallic mineral deposits are formed as a result of regional metamorphism.The source materials are rock constitutions that have undergone recrystallization or re-combination, or both. Rarely, water or carbon dioxide has been added, but other new constitutions are not introduced as they are in contact metasomatism deposits.

The enclosing rocks are wholly or in part metamorphosed; it is the rock metamorphism that has given rise to the deposits. The chief deposits thus formed are asbestos, graphite, talc, soapstone, andalusite-kyanite-sillimanite, dumortieritea, garnet, and possibly some emery.

a) Asbestos forms by the metamorphism (hydration) of ultrabasic igneous rocks – peridotites and dunites.
b) Graphite forms by regional metamorphism of organic matter, crystallization from igneous rocks, contact metamorphism and hydrothermal solutions.
c) Talc, soapstone and pyrophyllite form by a mild hydrothermal metamorphism of magnesian minerals eg tremolite, actinolite, olivine, epidote and mica. Talc also occurs in regionally metamorphosed limestones, altered ultrabasic igneous rocks, and contact metamorphic zones.
d) Andalusite-kyanite-sillimanite – these minerals are high grade refractories. Kyanite is formed by the dynamothermal metamorphism of aluminous silicate minerals. Andalusite is formed by the pneumatolytic action on aluminous silicates. Sillimanite results from high temperature metamorphism of aluminous crystalline rocks.
e) Garnet forms during the regional and contact metamorphism and is consequently found in schists and gneisses. It is also found as a constituent of igneous rocks.
f) Emery is a mixture of corundum and magnetite with hematite or spinel and is a product of contact metamorphism.

Bedded manganese deposits in parts of Madhya Pradesh and Maharashtra, primarily of sedimentary origin, have been subsequently affected by metamorphism. Braunite, a manganese silicate, is the important ore mineral besides several other oxide minerals.

Evaporation Process

Evaporation is an important mineral forming process, which supplies valuable materials used by the housewife, farmer, builder, chemist, engineer, manufacturer and even birds, beasts and plants.

- Great sections of the oceans may be cut off during slow oscillations of land and sea and be gradually evaporated to yield deposits of gypsum, common salt and potash.
- Ground waters reaching arid surfaces leave behind valuable minerals upon evaporation.
- Lakes may disappear under arid conditions to form playas.

Conditions of Formation:

- Evaporation proceeds most rapidly in warm humid climates. Evaporation o bodies of saline water leads to concentration of soluble salts, and when supersaturation is reached, the salts are precipitated.
- Deposition of minerals by evaporation depends on supersaturation, which in turn depends upon other factors, chief of which are:

    a) temperature
    b) pressure
    c) depositional environment, and
    d) seasonal & climatic changes

- Sea water is the prime source of minerals formed by evaporation. About 3.45% o which consists o dissolved salts of which 99.7% by wt. Is made up of only seven ions:
  Na^+ (30.61), Mg^{2+} (3.69), Ca^{2+} (1.16), K^+ (1.10), Cl^- (55.04), SO_4^{2-} (7.68) and $HCO3^-$ (0.41).
- About 45 other elements whose concentration is known in sea water occur as trace minerals in evaporites.
- Few carbonates occur in marine evaporites as compared to terrestrial evaporites. Calcite, dolomite and magnesite are the chief carbonates of marine evaporites.

Deposition from Oceanic Waters:

- The salts of oceanic waters are mainly obtained from the weathering of terrestrial rocks. Rain water carries soluble salts from continental areas to the oceans, evaporates, leaving behind the salts, to return to the continents as more rain.
- Small mounts are contributed by submarine volcanism, and by solution from oceanic rocks.
- The total amount of salts in the ocean is estimated to be 21.8 million km^3, enough to form 60 m thick layer over the ocean bottom. Of this common salt would constitute 47.5 m, $MgCl^2$ 5.8 m, $MgSO^4$ 3.9 m, $CaSO^4$ 2.3 m and the remaining salts 0.6 m.
- The rivers of the world are estimated to contribute 4 billion tons of salt to the ocean annually.
- Ocean water also contains gold, silver, base metals, manganese, aluminum, vanadium, nickel, cobalt as well as iodine, fluorine, phosphorous, uranium, arsenic, lithium, rubidium, cesium, barium and strontium.
- Of these, iodine concentrates in sea weeds, copper in shellfish, manganese, copper, nickel and other metals in nodules which alone have become concentrated into potentially commercial deposits.
- To attain the necessary conditions to induce precipitation, bodies of sea water must become isolated from the ocean in places where evaporation exceeds inflow. Such isolation may be effected by:

  a) formation of barrier reefs
  b) cutoffs near coasts where sills or reefs isolate sinking inland basins
  c) formation of sand bars

- If the original body of water contained 100 km^3 of water and this were to be concentrated to 50 km^3, the iron oxide and calcium carbonate present would be precipitated. The water would still contain 3500 million tons of salt of which 2700 million tons would be common salt.
- If evaporated to 20 km^3, gypsum would be precipitated. When the volume reaches about 10 km^3, common salt would be deposited.
- Subsequent evaporation would bring about deposition of magnesium sulfate and chloride followed by the bittern salts.

Deposition from Salt Lakes:

- The deposits formed from the evaporation of salt lakes are similar to those obtained from ocean water because salt lakes contain the same salts as the ocean, but generally in greater proportions.

- The relatively small size of lakes makes them more responsive to climatic changes resulting in greater fluctuations of deposition.
- Evaporites formed during periods of dessication may be redissolved during periods of subsequent expansion.
- Since lakes constantly receive new supplies of fresh water, salts and sediments, their deposits are generally thin bedded alternations of impure salts and clays.
- On salt playas, desert winds distribute sands and silt upon which later salts may be deposited during subsequent lake periods.
- Examples of deposits from salt lakes are:

  a) Basin and Rang Province, USA
  b) Salton area of the Imperial Valley, California
  c) Salt pans throughout Central Asia and northern Africa

Deposition from Groundwater:

- Evaporation of groundwater is universal and in arid regions the evaporites may accumulate as long as the climate remains dry.
- Groundwater contains salts similar to those of the ocean and salt lakes but their concentration is low and the proportion of individual salts may vary according to the character of the soil, bedrock, topography and climate.
- Calcium carbonate is almost always present; magnesium, sodium, potassium, iron and manganese compounds are common. Silica, phosphorous and locally boron and iodine are relatively abundant.
- Deposition ensues when evaporation occurs at or near the surface, or in caves. If the site of evaporation is fed by fresh supplies of groundwater, extensive deposits may eventually result.
- Evaporation of groundwater will proceed most rapidly where it is supplied relatively close to the surface viz., valley bottoms, slopes where hills and valleys merge, and long hill slopes interrupted by gentler or reverse grades.
- Deposits of economic importance are:

  a) nitrate salts with iodine
  b) boron
  c) calcium and sodium carbonate
  d) common salt
  e) Gauber's salt
  f) soda
  g) epsom salts
  h) borax

- Artificial brines are obtained by pumping water down wells drilled into rock salt beds, and the brines so formed are the main source of common salt production in the US. Potash is also obtained in this manner.

Deposition from Hot Springs:

- Substances contained in hot-spring waters build up deposits around their orifices. A few of theses are of commercial importance, the others are scenically beautiful.

- Their deposition is not always the result of evaporation alone, microscopic organisms help deposit some substances, and the escape of carbon dioxide under reduced surface pressure also causes deposition.
- The chief substances deposited in this manner are calcium carbonate, in the form of tufa, travertine, or calcareous sinter; silica in the form of siliceous sinter or geyserite; iron oxide in the form of ocher; and manganese dioxide in the form of wad.
- Many other non-metallic and metallic substances are deposited from hot springs but in relatively small amounts.

Sublimation Process

Process by which solid material passes into gaseous state without first becoming liquid. **Sublimation** is a **process** of mineral **deposits** associated with volcanism, thermal springs and fumaroles where volatilised matter is redeposited at lower temperature and pressure.

Module II

IRON ORE

Introduction

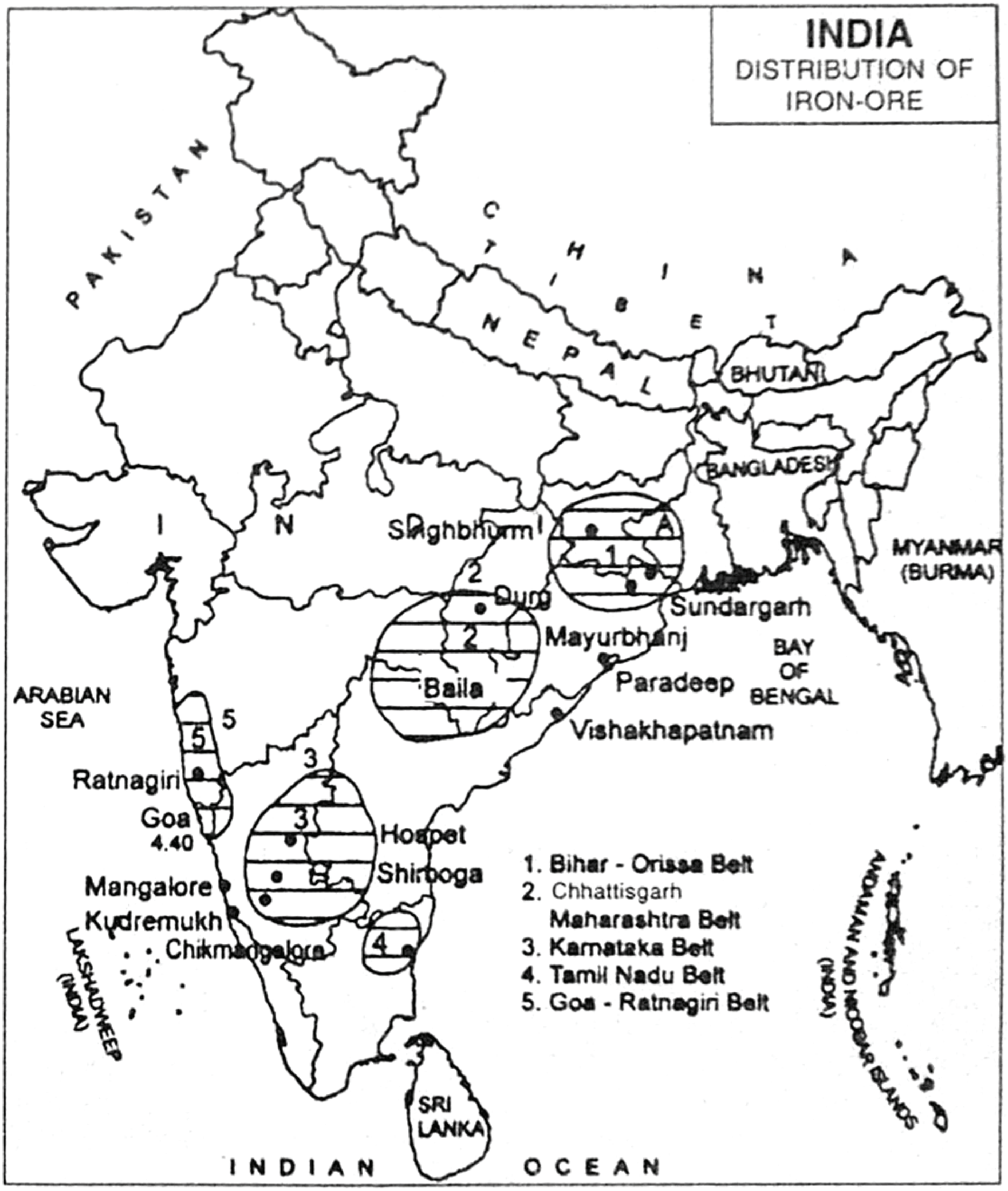
Iron ore is the most important mineral that is used to extract metallic Iron by Iron and Steel Industry. Extracted metal is widely used by secondary industries for manufacturing of machines, machine tools, construction of buildings etc. It is the most widely used metal because of its certain qualities like hardness, strength and durability. Further, iron is malleable and possess magnetic properties. Hence, Iron, because of its significance in manufacturing and development of infrastructure has wide economic importance.

Iron Ore Types

The iron ore is found in following four types:

1. **Magnetite**: It is the most important and best kind of iron ore. It contains about 72 percent metallic iron in it. It is black in colour.
2. **Hematite**: It is also an important source. It contains about 60-70 percent metallic iron in it. It is red and brown in colour.
3. **Limonite**: It contains about 30 to 40 percent metallic iron in it. It is mostly yellow in colour. It is a low-grade iron ore.
4. **Siderite**: It has more impurities. It contains about 48 percent metallic iron content in it. It is brown in colour. It contains a mixture of iron and carbon. It is a low-grade iron ore.

Geographic Distribution of Iron Ore in India
India is one of the richest countries of the world in iron ore deposits, particularly the hematite ore. According to the latest Indian Year Book, 95 percent of the hematite resources are distributed in Odisha, Jharkhand, Karnataka and Goa. Magnetite resources are estimated at around 10,619 million tons out of which only 59 million tons is situated mainly in Goa, Rajasthan and Jharkhand. The rest 10,560 million tons or the 99 percent of the magnetite resource is in 'Remaining Resources' category which is mainly found in Karnataka (74 percent) and Andhra Pradesh (14 percent).


INDIA
DISTRIBUTION OF
IRON-ORE
PAKISTAN
CHINA
TIBET
NEPAL
BHUTAN
BANGLADESH
MYANMAR
(BURMA)
INDIA
Singhbhum
1
2
Durg
Sundargarh
Mayurbhanj
2
Baila
Paradeep
Vishakhapatnam
BAY
OF
BENGAL
ARABIAN
SEA
5
5
Ratnagiri
Goa
4.40
3
3
Hospet
Shiroga
Mangalore
Kudremukh
Chikmagalore
4
LAKSHADWEEP
(INDIA)
ANDAMAN AND NICOBAR ISLANDS
(INDIA)
SRI
LANKA
INDIAN OCEAN
1. Bihar - Orissa Belt
2. Chhattisgarh
Maharashtra Belt
3. Karnataka Belt
4. Tamil Nadu Belt
5. Goa - Ratnagiri Belt

Iron Ore reserves (in descending order)

1. Karnataka
2. Odisha
3. Jharkhand
4. Chhattisgarh

Iron Ore production (in descending order)

1. Odisha
2. Goa
3. Karnataka
4. Chhattisgarh

The iron ore is widely distributed in the country:

Jharkhand

The iron ores here exist as hill masses which are close to coal fields. The iron ore generally occurs at the top of the hills, iron ore mining companies use aerial ropeways for bringing down the ore and pumping it into the railway wagons standing near the foot of the hills. The major iron ore mining areas in Jharkhand are Noamudi, Gua, Jamda and Kiriburu.

Chhattisgarh

Exploitable rich iron deposits are located in Dalli-Rajhara region of Durg district (close to Bhilai Steel Works), Bailadilla region of Dantewada district, Arindogi region and Raoghat region.

Odisha

The major iron ore mining centre is in Singhbhum district. The districts of Keonjhar, Mayurbhanj and Sundargarh also form the richest reserves of quality iron ore. The iron ore available here is Hematite which has about 60-70 percent metallic iron content. The iron ore from these sites is supplied to the iron and steel factories located at Rourkela, Jamshedpur, Asansol and Durgapur. The ore is also exported to different countries through the Paradip port.

Goa

The major iron ore mining centres are Sanguem, Safari, Ponda, Sahqualim, Bicholim and Quepem. The iron ore found in Goa is of high quality. The mining centres are located close to the port of Marmagao. The mines are worked by open-cast methods. They are close to rivers which enter the sea near the port. The iron ore is brought by road to jetties on the navigable rivers from which it is taken away to port for onward journey.

Karnataka

In Karnataka, the major iron ore mining areas are Baba Budan Hills, Kudremukh region, Hospet, Bellary, Chitradurga and Tumkur district. Iron-ore mined in Bellary and Hospet area is transported to Hospet from where it is sent to the ports of Chennai and Marmagao through railways for export to other countries.

Maharashtra

Maharashtra produces a very small amount of iron ore. Major mining ore areas include Chandrapur, Ratnagiri and Bhandara districts.

Andhra Pradesh

Iron ore is mined in small quantities in districts of Karimnagar, Warangal, Cuddapah, Kurnool, Adilabad and Anantapur.

Tamil Nadu

In Tamil Nadu, the areas where iron ore is mined are Tirthamalai Hills in Salem district and Yadpalli and Killiomalai areas in Nilgiris.

Uses

The primary use of iron ore is in the production of iron. Most of the iron produced is then used to make steel. Steel is used to make automobiles, locomotives, ships, beams used in buildings, furniture, paper clips, tools, reinforcing rods for concrete, bicycles, and thousands of other items. It is the most-used metal by both tonnage and purpose.

MANGANESE ORE

Introduction

Manganese occurs as silvery grey in colour and is very hard and brittle in nature. It is always available in combination with iron, laterite and other minerals. Manganese in alloy form is an essential input in steel making and is one of the most important metals in an industrial economy. Manganese ores of major commercial importance are: (i) pyrolusite (MnO2 , Mn about 63.2%); (ii) psilomelane (manganese oxide, containing water and varying amounts of oxides of Ba, K and Na as impurities; Mn commonly 45-60%); (iii) manganite (Mn2O3 . H2O, Mn about 62.4%); and (iv) braunite (3Mn2O3 , MnSiO3 , Mn about 62% and SiO2 about 10%). Indian manganese ore deposits occur mainly as metamorphosed bedded sedimentary deposits associated with Gondite Series (Archaeans) of Madhya Pradesh (Balaghat, Chhindwara & Jhabua districts), Maharashtra (Bhandara & Nagpur districts), Gujarat (Panchmahal district), Odisha (Sundergarh district) and with Kodurite Series (Archaeans) of Odisha (Ganjam & Koraput districts) and Andhra Pradesh (Srikakulam & Visakhapatnam districts).

Types of ore

Pyrolusite: MnO2 · Psilomelane: MnO. MnO2.H2O 6 · Manganite: MnO3 .H2O · Rhodochrosite: Mn CO3 · Hausmanite: Mn3O4 · Jacobsite: MnFe2O4 · Cryptomelane: K2 Mn8O18 · Hollandite: Ba2Mn3O16 · Nsutite (MN4+Mn2+) (O, OH) 2 · Braunite: 3Mn2O3. MnSiO3 · Todorkite 3MnO2 (Na,Mn)(OH)2.xH2O · Lithiophorite (Al,Li)(OH)2. MnO · Vrendenburgite 3Mn3O4.2Fe3O4 · Nsutite Mn4+0.85O1.7Mn2+0.15(OH)0.3 · Bixbyite (Mn,Fe)2O3. · Rhodonite (Mn, Fe, Mg, Ca)SiO3 · Birnessite (Ca,Na)(Mn2+Mn4+)7O14.3H2O

Occurrence

Manganese ores commonly exhibit the following textural features:

STALACTITIC: Elongated forms of manganese minerals deposited from solution by slowly dripping water

BANDED: Containing alternate bands of silicate mineral and manganese ore

BEDDED ORE: Consisting of alternate layers of host rock and manganese ore

OOLITIC/PISOLITIC: Spherical grains of manganese minerals composed of concentric layers of diameter 0.25–2 mm are oolites; rocks composed of concentric layers larger than 2 mm are called pisolites

CAVITY FILLING: Growth of crystals on the walls of planar fractures in rocks, with the crystal growth generally occurring normal to the walls of the cavities

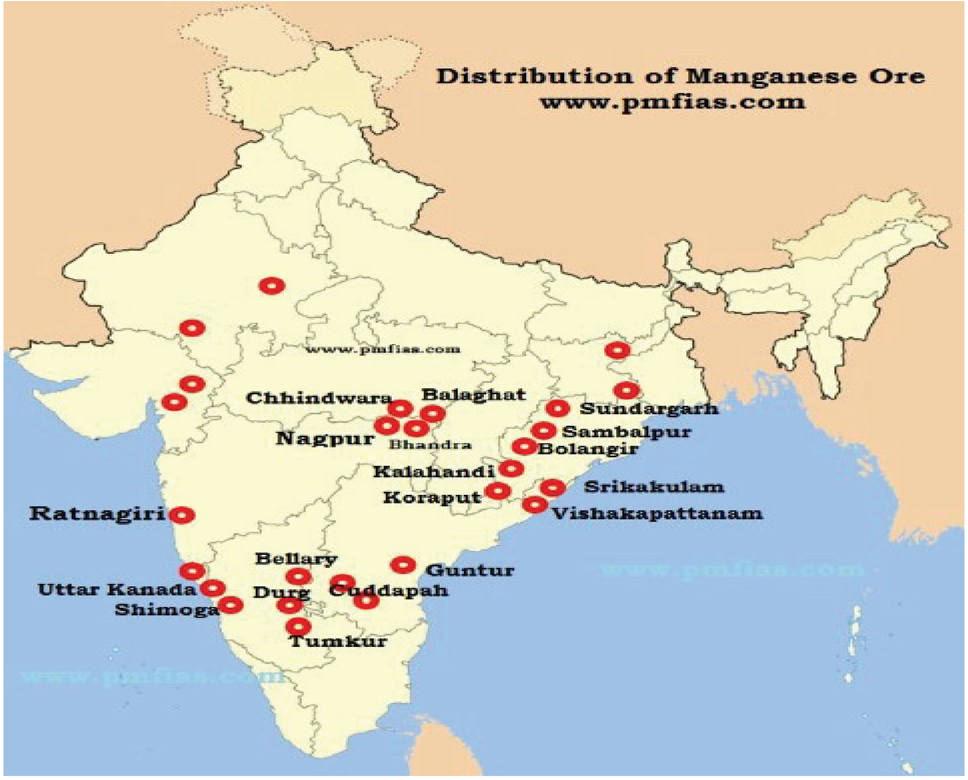
Stalactitic, banded, oolitic/pisolitic , cavity filling and bedded ore

Manganese Ore Distribution in India

- India processes **second** largest reserves in the world after **Zimbabwe**; 430 million tonnes
- India is the world’s **fifth largest producer** after China, Gabon, South Africa and Australia.
- *Maharashtra, Madhya Pradesh, Odisha, Andhra Pradesh* and *Karnataka* are the major manganese ore producing states.
- **Maharashtra** and **Madhya Pradesh** together produce more than half of India’s manganese

State wise reserves of Manganese

- **Odisha (44%)**,
- Karnataka (22%),
- Madhya Pradesh (13%),
- Maharashtra (8%),
- Andhra Pradesh (4%)
- Jharkhand and Goa (3% each),
- Rajasthan, Gujarat and West Bengal (remaining 3 per cent).



Maharashtra

- Produces about 27.66 per cent of Indian manganese.
- The main belt is in Nagpur and Bhandara districts.
- High grade ore is found in Ratnagiri district also.

Madhya Pradesh

- Produces about 27.59 per cent of India’s manganese ore.
- The main belt extends in Balaghat and Chhindwara districts.
- It is just an extension of the Nagpur Bhandara belt of Maharashtra.

Odisha

- 24 per cent production. [1st in reserves but 3rd in prduction]
- **Gondite** [regional names] deposits occur in Sundargarh district and **Kodurite** and **Khondolite** deposits in Kalahandi and Koraput Districts.
- Manganese is also mined from the lateritic deposits in Bolangir and Sambalpur districts

Andhra Pradesh

13% of India's manganese production.

- Srikakulam and Vishakhapatnam districts.
- Srikakulam district has the distinction of being the earliest producer (1892) of manganese ore in India.
- Cuddapah, Vijayanagaram and Guntur are other manganese producing districts.

Karnataka

- 6 per cent of India's manganese.
- Uttara Kannada, Shimoga, Bellary, Chitradurg and Tumkur districts.

Other producers

- Goa,
- Panchmahals and Vadodara in Gujarat,
- Udaipur and Banswara in Rajasthan and
- Singhbhum and Dhanbad districts in Jharkhand are other producers of manganese.

USES

Manganese is the most important ferro alloy metal, essentially employed in the manufacture of high – manganese steels and also carbon steels. 95% of Manganese is used for metallurgical purposes and minor amounts in the manufacture of alloy like bronze. Manganese is essential to iron and steel production by virtue of its sulfurfixing, deoxidizing and alloying properties. Among a variety of other uses, manganese is a key component of low-cost stainless steel formulations. Small amounts of manganese improve the workability of steel at high temperatures. In the iron and steel industry, manganese ore containing 28 to 35% manganese is used. Ore size generally varies from 10 to 40 mm. For manganese ore used in ferro-manganese industry, besides manganese content, other important considerations are high manganese to iron ratio and a very low content of harmful phosphorus.

ALUMINIUM ORE

INTRODUCTION

Bauxite ore is the world's primary source of aluminum. The ore must first be chemically processed to produce alumina (aluminum oxide). Alumina is then smelted using an electrolysis process to produce pure aluminum metal. Bauxite is typically found in topsoil located in various tropical and subtropical regions. The ore is acquired through environmentally responsible strip-mining operations. Bauxite reserves are most plentiful in Africa, Oceania and South America. Reserves are projected to last for centuries.

ORE

Bauxite is basically an aluminous rock that contains hydrated aluminium oxide as main constituent and iron oxide, silica & titania as minor constituents present in varying proportions. Hydrated aluminium oxides present in the bauxite ore are diaspore and boehmite, Al2O3 .H2O (Al2O3 -85%; Al-45%); gibbsite or hydrargillite, Al2O3 .3H2O (Al2O3 - 65.4%; Al-34.6%), and bauxite (containing colloidal alumina hydrogel), Al2O3 .2H2O (Al2O3 -73.9%; Al-39.1%). The iron oxide in bauxite ore is present as haematite or goethite; silica as clay; and free quartz & titania as leucoxene or rutile. Bauxite is the principal ore of aluminium which is one of the most important non-ferrous metals used in the modern industry. It is also an essential ore for Refractory and Chemical industries. The country has 3,896 million tonnes of resources of bauxite which is sufficient to meet both domestic and export demands.

DISTRIBUTION

The total in situ reserves are 3,076 million tonnes as on 1 April, 2000. These deposits are mainly associated with laterites and occur as blankets or cappings on hills and plateaus except in coastal areas of Gujarat and Goa. The major occurrences have been reported from Jharkhand, Chhattisgarh, M.P., Orissa, Gujarat, Karnataka, Tamil Nadu and Andhra Pradesh.

Jammu and Kashmir, Kerala, U.P. and Rajasthan are also reported to have some bauxite deposits. The production of bauxite has increased rather out of proportion from a mere 68 thousand tonnes in 1950-51 to a staggering quantity of 9,777 thousand tonnes in 2002-03 recording an increase of over 140 times in a span of about half a century. Orissa, Gujarat, Jharkhand, Maharashtra, Chhattisgarh, Tamil Nadu and Madhya Pradesh are the main bauxite producing states in India.

1. Orissa:

Orissa is the largest bauxite producing state accounting for more than half of the total production of India. The total recoverable reserves in the state are estimated at 1,370.5 million tonnes. The main bauxite belt is in Kalahandi and Koraput districts and extends further into Andhra Pradesh.

This 300 km long, 40 to 100 km wide and 950 to 1300 metre thick belt is the largest bauxite bearing region of the country. The main deposits occur in Kalahandi, Koraput, Sundargarh, Bolangir and Sambalpur districts.

The important mining areas include Chandgiri, Baphalimoli Parbat, Kathakal, Manjimali, Pasenmali, Kunnumali, Kodingandi, Pottangi and Karalput in Kalahandi and Koraput districts. The new aluminium plant at Damanjoli provides ready market for bauxite of this area. The proposed aluminium plant at Doragurha will provide further impetus.

2. Gujarat:

Gujarat is the second largest producer and produces over 15 per cent of the total bauxite of India. The total reserves are estimated at 87.5 million tonnes mainly found in Jamnagar, Junagadh, Kheda, Kuchchh, Sabarkantha, Amreli and Bhavnagar. The most important deposits occur in a belt which is 48 km long and 3 to 4.5 km wide lying between the Gulf of Kachchh and the Arabian Sea through Bhavnagar, Junagadh and Amreli districts.

3. Jharkhand:

The reserves of all grades of recoverable bauxite in Jharkhand have been estimated at 63.5 million tonnes. These reserves are found in extensive areas of Ranchi, Lohardaga, Palamu and Gumla districts. Some bauxite is also found in Dumka and Munger districts. High grade ore occurs in Lohardaga and adjoining areas.

4. Maharashtra:

Maharashtra accounts for about 10 per cent of the total bauxite produced in India. The total recoverable reserves in the state have been estimated to be of the order of 87.7 million tonnes. The largest deposits occur in Kolhapur district capping the plateau basalts. Udgeri, Dhangarwadi, Radhanagari and Inderganj in Kolhapur district contain rich deposits with alumina content 52 to 89 per cent. The other districts with considerable deposits are Thane, Ratnagiri, Satara and Pune.

5. Chhattisgarh:

Chhattisgarh produces more than 6 per cent bauxite of India. The Maikala range in Bilaspur, Durg districts and the Amarkantak plateau regions of Surguja, Raigarh and Bilaspur are some of the areas having rich deposits of bauxite.

6. Tamil Nadu:

The total reserves of bauxite in Tamil Nadu are estimated at 17.2 million tonnes mainly found in Nilgiri, Salem and Madurai districts. Nilgiri and Salem are the main bauxite producing districts enabling Tamil Nadu to contribute slightly more than 2 per cent of the India’s bauxite.

7. Madhya Pradesh:

Amarkantak plateau area, the Maikala range in Shahdol, Mandla and Balaghat districts and the Kotni area of Jabalpur district are the main producers.Some bauxite is also found in Andhra Pradesh, (Vishakhapatnam, East Godavari and West Godavari), Kerala (Kannur, Kollam and

Thiruvananthapuram), Rajasthan (Kota), Uttar Pradesh (Banda, Lalitpur and Varanasi), Jammu and Kashmir (Jammu, Poonch, Udhampur) and Goa.

Uses:

Aluminium is used in a huge variety of products including cans, foils, kitchen utensils, window frames, beer kegs and aeroplane parts. This is because of its particular properties. It has low density, is non-toxic, has a high thermal conductivity, has excellent corrosion resistance and can be easily cast, machined and formed. It is also non-magnetic and non-sparking. It is the second most malleable metal and the sixth most ductile.It is often used as an alloy because aluminium itself is not particularly strong. Alloys with copper, manganese, magnesium and silicon are lightweight but strong. They are very important in the construction of aeroplanes and other forms of transport.
Aluminium is a good electrical conductor and is often used in electrical transmission lines. It is cheaper than copper and weight for weight is almost twice as good a conductor.

When evaporated in a vacuum, aluminium forms a highly reflective coating for both light and heat. It does not deteriorate, like a silver coating would. These aluminium coatings have many uses, including telescope mirrors, decorative paper, packages and toys.

Copper Ore

Introduction:

Native copper is an element and a mineral. It is found in the oxidized zones of copper deposits; in hydrothermal veins; in the cavities of basalt that have been in contact with hydrothermal solutions; and as pore fillings and replacements in conglomerates that have been in contact with hydrothermal solutions. It is rarely found in large quantities, thus it is seldom the primary target of a mining operation. Most copper produced is extracted from sulfide deposits.

Mineralogy:

The main copper sulphide minerals are chalcopyrite (CuFeS2) chalcocite (Cu2S), covellite (CuS), bornite (Cu5FeS4), tetrahedrite ((Cu,Fe)12Sb4S13) and enargite (Cu3AsS4). The largest source of copper is from porphyry ore deposits in which one or a combination of the aforementioned minerals occurs.

Distribution:

1. Madhya Pradesh:

Madhya Pradesh has become the largest producer of copper in India surpassing Karnataka, Rajasthan and Jharkhand in succession. In the year 2002-03 the state produced 56.86 per cent of the total copper production of the country.

The state is blessed with a fairly large belt in Taregaon area, in Malanjkhand belt of Balaghat district. This district has recoverable reserve of 84.83 million tonnes of copper ore having 1,006 thousand tonnes of metal. Reserves of moderate size are also found in Kherlibazar- Bargaon area of Betul district. Some other areas are also reported to have copper ore reserves.

2. Rajasthan:

Rajasthan has also progressed a lot with respect to production of copper and is now the second largest producing state in India accounting for over 40 per cent of the total production of the country. Most of the copper reserves are found along the Aravali range.

A total of recoverable reserve in the state, spread over the districts of Ajmer, Alwar, Bhilwara, Chittaurgarh, Dungarpur, Jaipur, Jhunjhunu, Pali, Sikar, Sirohi and Udaipur are estimated at 65.08 million tonnes from which 613.55 thousand tonnes of metal is expected to be obtained.

The Khetri-Singhana belt in Jhunjhunu district is the most important copper producing area. This belt runs in north-east to south-west direction over a distance of 80 km from Singhana to Raghunathgarh with average width varying from 3 to 5 km.

The annual output of copper ore at Khetri is 1.8 million tonnes yielding around 16,000 tonnes of metal. The Kho-Dariba area about 48 km to the south-west of the Alwar city and Delwara-Kirovli area about 30 km from Udaipur are other important producers. In Kishangarh area of Ajmer district, 2.5 million tonnes of copper ore, having 0.60 per cent copper, have tentatively been estimated.

3. Jharkhand:

Jharkhand, earlier a part of Bihar used to be the largest producer of copper till early 1980s but it has lost much importance and has slipped to third position, partly due to fall in its own production and mainly due to increased production of other states. The state s share of copper ore production has fallen from 62 per cent of the nation’s total production in 1977-78 to a desperate 23 per cent in 2002-03.

The main copper belt extends over a distance of 130 km. Singhbhum is the most important copper producing district where Rakha, Kendadih, Surda, Dhobani, Mosabani and some other areas have proved reserves of 58.044 million tonnes from which 1,480.12 thousand tonnes of metal may be recovered. Hasatu, Baraganda, Jaradih, Parasnath, Barkanath, etc. in Hazaribagh district; Bairakhi in Santhal Parganas area and some parts of Palamu and Gaya districts are also reported to have some deposits of copper ore.

Imports:

The production of copper ore in the country always falls short of our requirements and India has to import copper from other countries. The major part of supply comes from the USA. Canada, Zimbabwe, Japan and Mexico. The quantity of import varies from year to year depending upon demand and supply.

Uses:

Native copper was probably one of the early metals worked by ancient people. Nuggets of the metal could be found in streams in a few areas, and its properties allowed it to be easily worked without a required processing step. Today most copper is produced from sulfide ores.

Copper is an excellent conductor of electricity. Most copper mined today is used to conduct electricity - mostly as wiring. It is also an excellent conductor of heat and is used in cooking utensils, heat sinks, and heat exchangers. Large amounts are also used to make alloys such as brass (copper and zinc) and bronze (copper, tin, and zinc). Copper is also alloyed with precious metals such as gold and silver.

Module-3

Mineral reserves of India

India is blessed with diverse kind of mineral reserves. On the basis of chemical and physical properties, minerals are grouped as −

1. **Metallic** minerals
2. **Non-metallic** minerals.

- Major examples of metallic minerals are iron ore, copper, gold, etc.

Iron

Copper

Gold

Metallic minerals are further sub-divided as ferrous and non-ferrous metallic minerals.

The minerals containing iron is known as ferrous and without iron is known as non-ferrous (copper, bauxite, etc.).

Depending upon the origination, non-metallic minerals are either organic (such as fossil fuels also known as mineral fuels, which are derived from the buried animal and plant, e.g. such as coal and petroleum), or inorganic minerals, such as mica, limestone, graphite, etc.

Distribution of Minerals

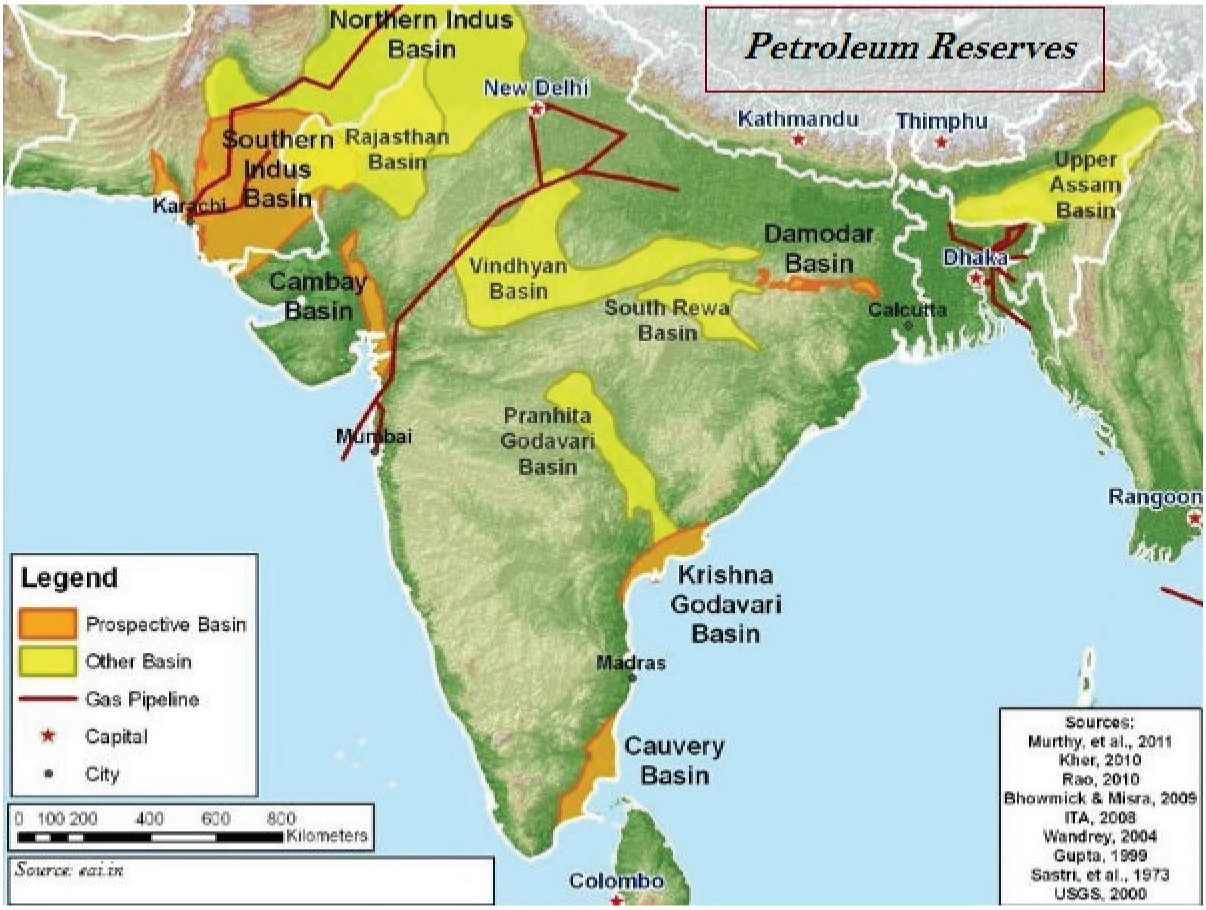
Minerals are unevenly distributed on the earth's surface.

All minerals are exhaustible in nature, i.e., will exhaust after a certain time.

However, these minerals take long time to form, but they cannot be replenished immediately at the time of need.

More than 97% of coal reserves occur in the valleys of Damodar, Sone, Mahanadi, and Godavari rivers.

Petroleum reserves in India are located in the sedimentary basins of Assam, Gujarat, and Mumbai High (i.e. off-shore region in the Arabian Sea – shown in the map given below).



Source: eai.in

Some new petroleum reserves are also found in the Krishna-Godavari and Kaveri basins (shown in the image given above).

Mineral Belts in India

Further, there are three major mineral belts in India namely −

The North-Eastern Plateau Region,

The South-Western Plateau Region, and

The North-Western Region.

North-Eastern Plateau Region

The major areas of north-eastern plateau region are Chhotanagpur (Jharkhand), Odisha, West Bengal, and parts of Chhattisgarh.

Iron ore, coal, manganese, bauxite, and mica are the major minerals of the north-eastern plateau region.

South-Western Plateau Region

The south-western plateau region covers major parts of Karnataka, Goa, and contiguous Tamil Nadu uplands and Kerala.

Major mineral resources of south-western plateau region are iron ore, manganese, and limestone.

Kerala has deposits of monazite and thorium, and bauxite clay and Goa has deposits of iron ore.

North-Western Region

The north-western region covers the areas of Aravalli in Rajasthan and parts of Gujarat.

Major minerals of north-western regions are copper and zinc; other significant minerals include sandstone, granite, and marble, along with Gypsum and Fuller's earth deposits.

In addition, Gujarat and Rajasthan, both have rich sources of salt.

The Himalayan belt is also an important mineral belt, as it has rich deposits of copper, lead, zinc, cobalt, and tungsten.

Major Minerals

Following are the major minerals found in india −

Iron

About 95% of total reserves of iron ore is found in the States of Odisha, Jharkhand, Chhattisgarh, Karnataka, Goa, Telangana, Andhra Pradesh, and Tamil Nadu.

Sundergarh, Mayurbhanj, and Jhar are the major iron ore regions in Odisha and the important mines are Gurumahisani, Sulaipet, Badampahar (Mayurbhaj), Kiruburu (Kendujhar), and Bonai (Sundergarh).

Noamundi (Poorbi Singhbhum) and Gua (Pashchimi Singhbhum) are important mines in Jharkhand.

Dalli and Rajhara in Durg district are the important mines of Chhattisgarh.

Sandur-Hospet area of Ballari district, Baba Budan hills, and Kudremukh in Chikkamagaluru district, and parts of Shivamogga are the important iron ore regions in Karnataka.

The districts of Chandrapur, Bhandara, and Ratnagiri are the iron regions in Maharashtra.

Other iron ore regions in India are Karimnagar and Warangal district of Telangana, Kurnool, Cuddapah, and Anantapur districts of Andhra Pradesh, and Salem and Nilgiris districts of Tamil Nadu.

Manganese

Odisha is the leading producer of Manganese.

Bonai, Kendujhar, Sundergarh, Gangpur, Koraput, Kalahandi, and Bolangir are the major manganese regions in Odisha.

Dharwar, Ballari, Belagavi, North Canara, Shivamogga, Chitradurg, Tumkur, and Chikkmagaluru are major manganese regions in Karnataka.

Nagpur, Bhandara, and Ratnagiri districts are the major regions of manganese in Maharashtra.

Balaghat-Chhindwara-Nimar-Mandla, and Jhabua districts are the important manganese regions of Madhya Pradesh.

Bauxite

Odisha is the largest producer of Bauxite in India.

Kalahandi, Sambalpur, Bolangir, and Koraput are the leading producers of bauxite in Odisha.

Lohardaga (Jharkhand) is rich in bauxite deposits.

Amarkantak plateau has rich deposits of bauxite in Chhattisgarh.

Katni-Jabalpur area and Balaghat are the major regions of bauxite in Madhya Pradesh.

Kolaba, Thane, Ratnagiri, Satara, Pune, and Kolhapur in Maharashtra are important bauxite producers.

Copper

Copper deposits are largely concentrated in Singhbhum district of Jharkhand, Balaghat district of Madhya Pradesh, and Jhunjhunu and Alwar districts of Rajasthan.

Mica

Hazaribagh plateau of Jharkhand and Nellore district of Andhra Pradesh have deposits of high grade mica.

Jaipur to Bhilwara and areas around Udaipur are the major mica-bearing regions of Rajasthan.

Other mica-bearing regions are Mysore and Hasan districts of Karnataka; Coimbatore, Tiruchirapalli, Madurai, and Kanniyakumari of Tamil Nadu; Alleppey of Kerala; Ratnagiri of Maharashtra; Purulia and Bankura of West Bengal.

Mining Methods

Mining is the process used to extract valuable resources from the Earth. It is done to acquire any resource that cannot be grown or fabricated through artificial means. More specifically, mining is used to extract non-renewable resources like fossil fuels, minerals and even water.

There are four main methods of mining: underground, surface, placer and in-situ. The type of mining method used depends on the kind of resource that is being targeted for extraction, the deposit's location below or on the Earth's surface and the capacity of each method to profitably extract the resource. Each mining method also has varying degrees of safety and impacts on the surrounding environment, both of which are concerns for legitimate mining operations.

Each of the four mining methods are explained below.

Underground Mining

Relatively costly and frequently used to get to deeper deposits, underground mining involves digging down into the earth and creating tunnels and shafts that reach the deposits of resources. Ore and other resources can then be brought up to the surface for processing, while waste rock can be removed for disposal.

There are various types of underground mining that are categorized based on the kind of shafts used, the technique of extraction and the process used to get to a deposit. For instance, drift mining involves the use of horizontal tunnels, while slope mining uses diagonal shafts to access deposits.

The type of underground mining technique used is typically based on the geology of the area, especially the amount of ground support needed to make mining safe.

Surface Mining

Surface mining involves removal of plant life, soil and potentially bedrock to be able to access resource deposits. It is normally used for fairly shallow, non-precious deposits. The two foremost kinds of surface mining are open-pit mining and strip mining.

Open pit mining involves digging out rocks to form an open pit or borrow pit, from which resources are then extracted. An open pit mine generally has stepped sides to minimize the risks associated with collapse and a large ramp for mining equipment. Some kind of water management system is generally necessary to keep an active mine from turning into a lake. Open-pit mines are typically worked until either the mineral deposit is depleted, or various factors make the mine non-profitable. When this occurs, the open pit is often modified to become a landfill for solid wastes.

Strip mining is mostly used to extract shallow, "bedded" deposits, where a mineral layer is covered by a layer of soft topsoil and weathered rocks. The relatively soft top layer of earth is stripped by either a dragline or industrial shovel to uncover a deposit.

Placer Mining

Normally formed by weathering via water and/or wind action, placers are unconsolidated deposits of resources. Placer mining is generally done in riverbeds, sands or other sedimentary environments and involves sifting valuable materials from sediments. Famously, "panning for gold" can be part of the placer mining process. In placer operations, the extracted sedimentary material is rinsed and sluiced to pull out the desired minerals.

In addition to gold, gemstones, platinum, tin and other materials can be extracted via place mining. At least 50 percent the world's titanium comes from this type of mining operation.

In-Situ Mining

Also referred to as solution mining, in-situ mining does not involve removing intact ore from beneath the earth's surface. Instead, it involves pumping chemicals underground to dissolve resource-containing ore and then pumping what is known as the "pregnant solution" back up to the surface, where it can be processed to recover minerals. This technique is mainly used in uranium mining.

This technique causes very little disturbance to the surface and does not produce large amounts of waste rock. To use this technique, the ore body must be permeable to the extraction liquids, and it must be possible to complete the process without the significant risk of contaminating nearby groundwater.

Crystallography

Crystallography: Science that deals with the chemical and physical properties, structure, formation and applications of crystals as well as the mathematical law that governs crystal growth.

Crystals: A crystal is a homogenous solid, which is formed by a 3-D repeating unit (pattern of ions, atoms or molecules) with fixed distances.

Crystallography is a branch of mineralogy. Crystallography in simple meaning means "the study of crystals". At one time, the word crystal referred only to quartz crystal, but has taken on a broader definition, which includes all minerals with wellexpressed crystal shapes. Crystallography is divided into three sections - geometrical, physical and chemical. The latter two involve the relationships of the crystal form (geometrical) upon the physical and chemical properties of any given mineral.

A CRYSTAL is a regular polyhedral form, bounded by smooth faces, have a definite a chemical compound on account of its interatomic forces. A polyhedral form simply means a solid bounded by flat planes. "A chemical compound" tell us that all minerals are chemicals, just formed by and found in nature. The last half of the definition tells us that a crystal normally forms during the change of matter from liquid or gas to the solid state. In the liquid and gaseous state of any compound, the atomic forces that bind the mass together in the solid-state are not present. Therefore, we must first crystallize the compound before we can study its geometry. Liquids and gases take on the shape of their container; solids take on one of several regular geometric forms. These forms may be subdivided, using geometry, into six systems.

Laws of crystallography

Steno’s Law called the CONSTANCY OF INTERFACIA ANGLES

The law of the constancy of interfacial angles (also called the 'first law of crystallography') states that the angles between the crystal faces of a given species are constant, whatever the lateral extension of these faces and the origin of the crystal, and are characteristic of that species (Fig.1). It paved the way for Haüy's law of rational indices.

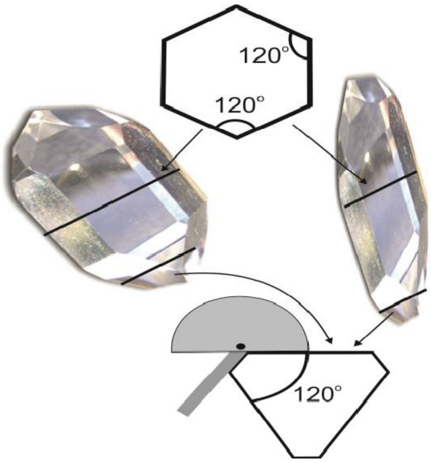


Fig. 1 Cross section along prism and rhombohedral faces indicating constancy of interfacial angles even if the quartz crystals is flattened along one axis.

Contact Goniometer: Consists of a printed protractor to which is attached an arm swiveling plastic that is pivoted at the center and with a hairline mark that can be read against the scale (see figure below). The goniometer is held with the straight edge of the protractor in contact with one face, the straight edge of the plastic strip in contact with the other face and with the plane surface of the protractor and the strip perpendicular to both crystal faces. Two values of the interfacial angle, which total 180o, can be read from the protractor. One is the internal angle; the other is the external angle.

The law of rational indices States that the intercepts, OP, OQ, OR, of the natural faces of a crystal form with the unit-cell axes a, b, c (see Figure 2) are inversely proportional to prime integers, h, k, l. They are called the Miller indices of the face. They are usually small because the corresponding lattice planes are among the densest and have therefore a high interplanar spacing and low indices (source: dictionary of Crystallography). Two crystals of the same substance may differ considerably in appearance that in number, size and shape of the individual faces. In order to describe the external form of crystals, a mathematical method of relating plane; to certain imaginary lines in space is used. The position of any plane can be uniquely fixed by the intercepts it makes on the axes of reference. The ratio of the distances from the origin, at which the crystal face cuts the crystallographic axes, is known as the ‘parameter of a crystal face’. In the above given figure, let OX, OY, OZ represents the crystallographic axes and ABC is a crystal face making intercepts of 'OA' on, 'OX', 'OB' on OY and 'OC' on 'OZ'. The parameters of the face ABC are given by the ratio of OA, OB, and OC. It is convenient to take the relative intercepts of this face as standard length for the purpose of representing the position of any other face such as

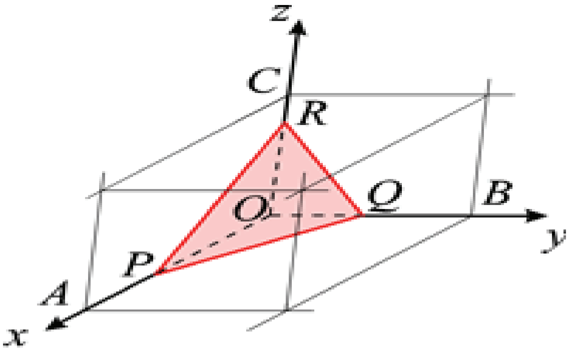


figure2

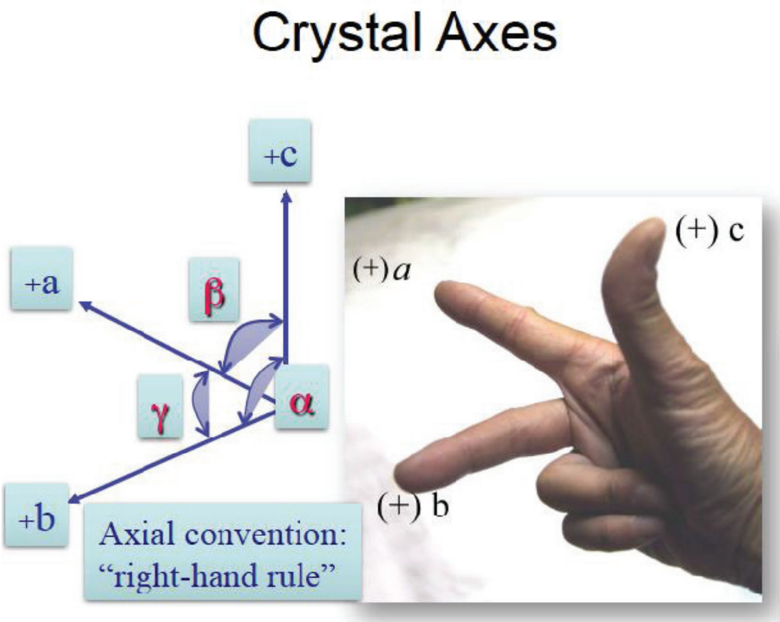
DEF. In this case OD=OA, 0E=20B, OF= ½OC. Therefore, the parameters are of DEF with reference to the standard face ABC. The reciprocals of the parameters are known as indices. According to the crystallographic notation by Miller a law- has been established, which states that "the intercepts that any face makes on the crystallographic axes are either infinite or small rational multiples of the intercepts made by the unit form". Hence, the ratio between the intercepts on the axes of different faces on a crystal can always be expressed by rational numbers as 1: 2, 1: 3, 1: 4.

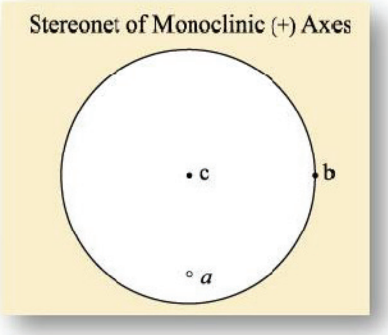
Law of axial-ratio This law states that 'the ratio between the lengths of the axes of the crystals of a given substance is- constant. This ratio is termed as 'axial-ratio'. Axial-ratio, which is the ratio of the lengths of the crystallographic, expressed in terms of one of the horizontal, axes, usually, '6'-axis, as unity. Haüy (1784, 1801) deduced the law of rational indices from the observation of the stacking laws required to build the natural faces of crystals by piling up elementary blocks. E.g. cubes to construct the {110} faces of the rhombdodecahedron observed in garnets or rhombohedrons to construct the scalenohedron of calcite or {210} faces of the pentagon-dodecahedron observed in pyrite.

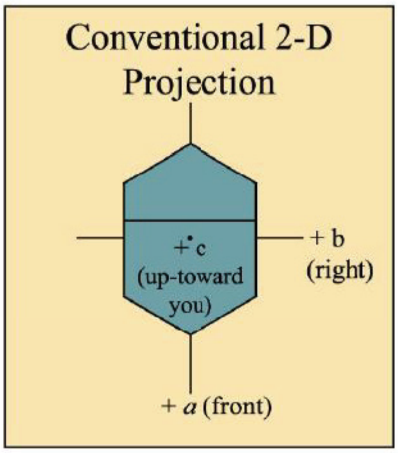
Law of crystallographic axes The positions of the crystallographic axes are more or less fixed by symmetry of the crystals, for in most crystals they are symmetry axes or normal to symmetry plane. It has been observed that "crystals of a given mineral can be referred to the same set of crystallographic axes". 3.5 Law of constancy of symmetry According to this law, all crystals of a substance have the same elements of symmetry i.e. plane of symmetry, axis of symmetry and center of symmetry.

Six Crystal systems

In order to obtain insight into the solid geometry of a crystal. We need describe the crystallographic axes. Since crystals are dealt in three dimensions, we need to have three axes. Let's for simplicity make them all equal and at right angles to each other. This is the simplest case to consider. The axes pass through the center of the crystal. We can describe the intersection of any given face with these 3 axes. The axes are called a, b and c. The interaxial angles as σ, β and γ (Fig. 3). The crystallographic axes are imaginary lines that we can draw within the crystal lattice. These will define a coordinate system within the crystal. For 3-dimensional space lattices we need 3 or in some cases 4 crystallographic axes that define directions within the crystal lattices. Depending on the symmetry of the lattice, the directions may or may not be perpendicular to one another, and the divisions along the coordinate axes may or may not be equal along the axes. Below figures shows the right hand convention rule name each axes of any crystal system.

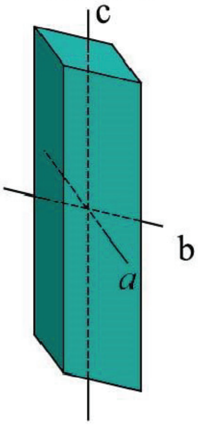






Crystal Axes

Triclinic

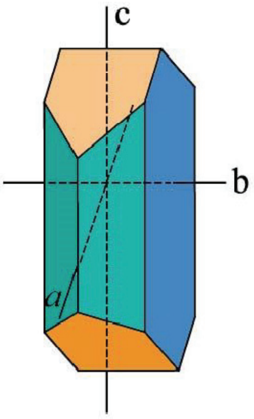


$a \neq \mathrm{b} \neq \mathrm{c}$

$\alpha \neq \beta \neq \gamma \neq 90$

The axes are chosen as parallel to the principal face intersections. There are no symmetric restrictions to the choice of ***a***, **b**, and **c**, but, by convention, the most pronounced zone is oriented vertically and the zone axis is **c**.

Monoclinic



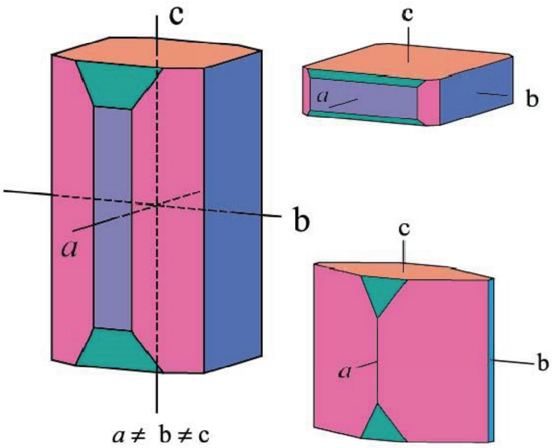
$a \neq \mathrm{b} \neq \mathrm{c}$

$\alpha = \gamma = 90, \beta \neq 90$

The axes are chosen as parallel to the principal face intersections. **b** is selected as || to the 2-fold axis or ⊥ to the mirror. The most pronounced zone is oriented vertically and the zone axis is **c**. ***a*** slopes down and forward so that β is typically > 90.

Crystal Axes

Orthorhombic

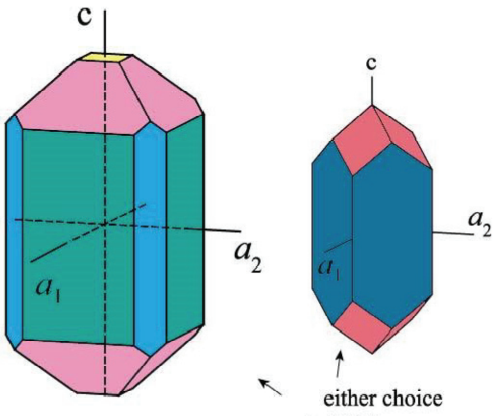


$a \neq \mathrm{b} \neq \mathrm{c}$

$\alpha = \beta = \gamma = 90$

The axes are mutually perpendicular and || to 2-fold axes (conventionally **c** < ***a*** < **b**). When crystals are elongated (as above left) **c** is chosen as the direction of elongation. When crystals are flattened (top insert)**,** **c** is chosen as normal to the predominant plane.

Tetragonal

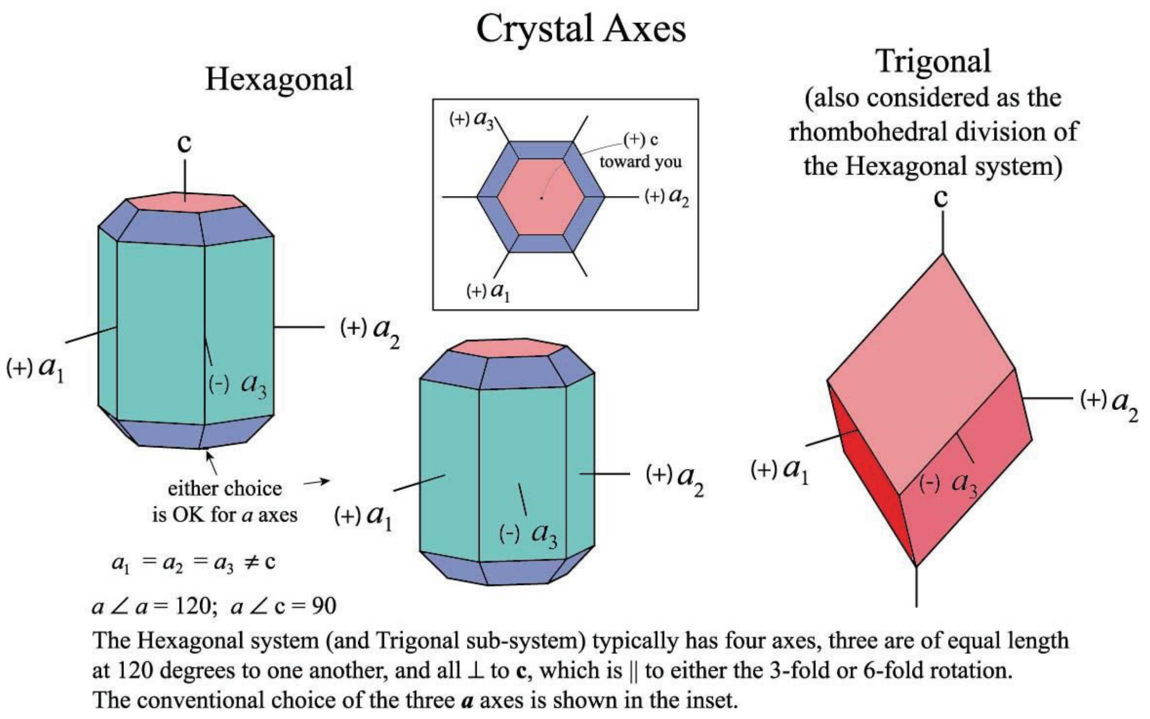


either choice is OK for *a* axes

$a_1 = a_2 \neq \mathrm{c}$

$\alpha = \beta = \gamma = 90$

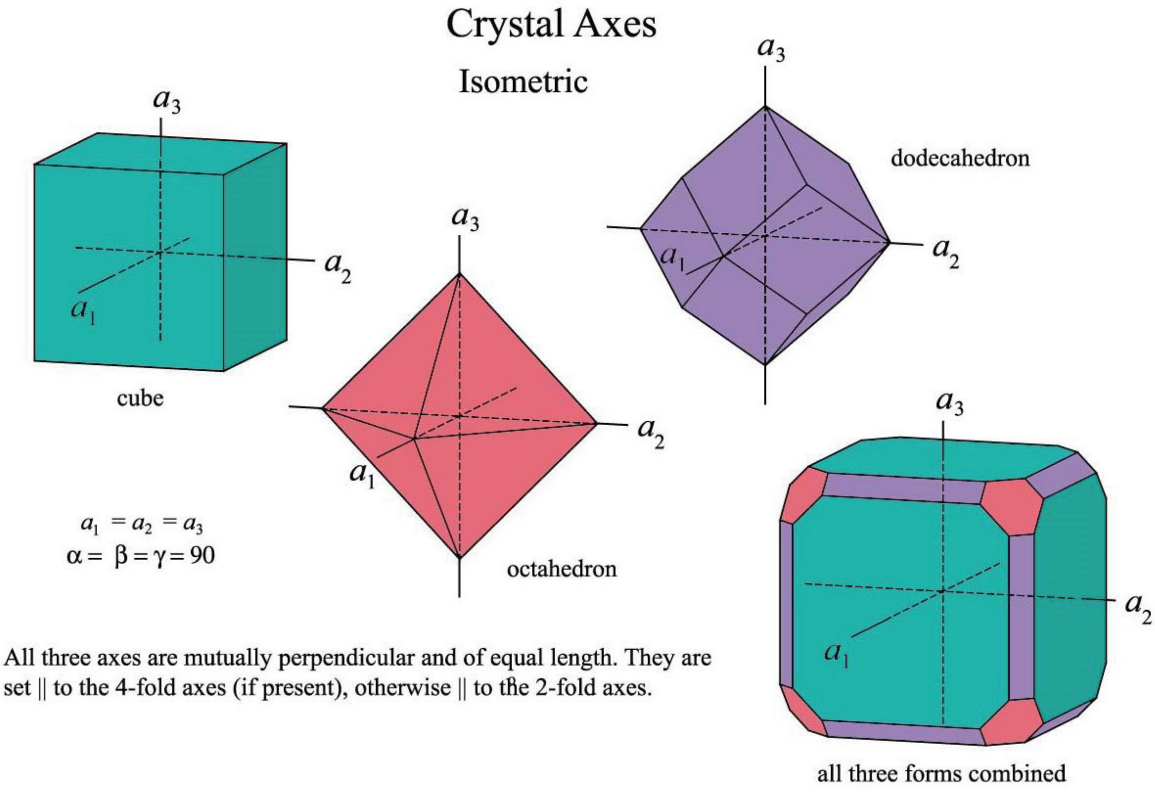
The axes are mutually perpendicular and **c** is chosen || to the 4-fold axis. Due to the 4-fold symmetry, the other two axes are equal. $\boldsymbol{a}_1$ is oriented toward the front and $\boldsymbol{a}_2$ to the right.



$a_1 = a_2 = a_3 \neq c$

$a \angle a = 120$; $a \angle c = 90$

The Hexagonal system (and Trigonal sub-system) typically has four axes, three are of equal length at 120 degrees to one another, and all ⊥ to **c**, which is || to either the 3-fold or 6-fold rotation. The conventional choice of the three ***a*** axes is shown in the inset.



$a_1 = a_2 = a_3$

$\alpha = \beta = \gamma = 90$

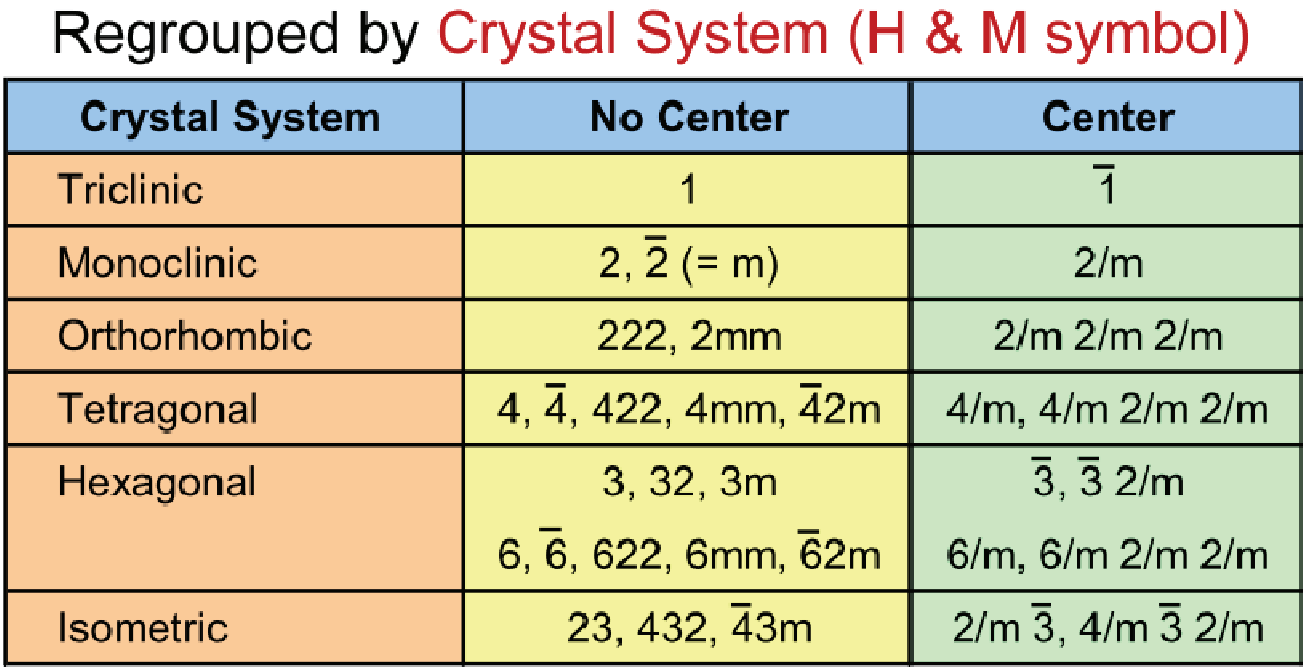
All three axes are mutually perpendicular and of equal length. They are set || to the 4-fold axes (if present), otherwise || to the 2-fold axes.

Symmetry: repetitive arrangement of features (faces, corners and edges) of a crystal around imaginary lines, points or planes. Reflects internal ordering of atoms in the mineral structure.

Motif: the fundamental part of a symmetric design that, when repeated creates the whole pattern.
Operation: some act that produces the motif to create the pattern.

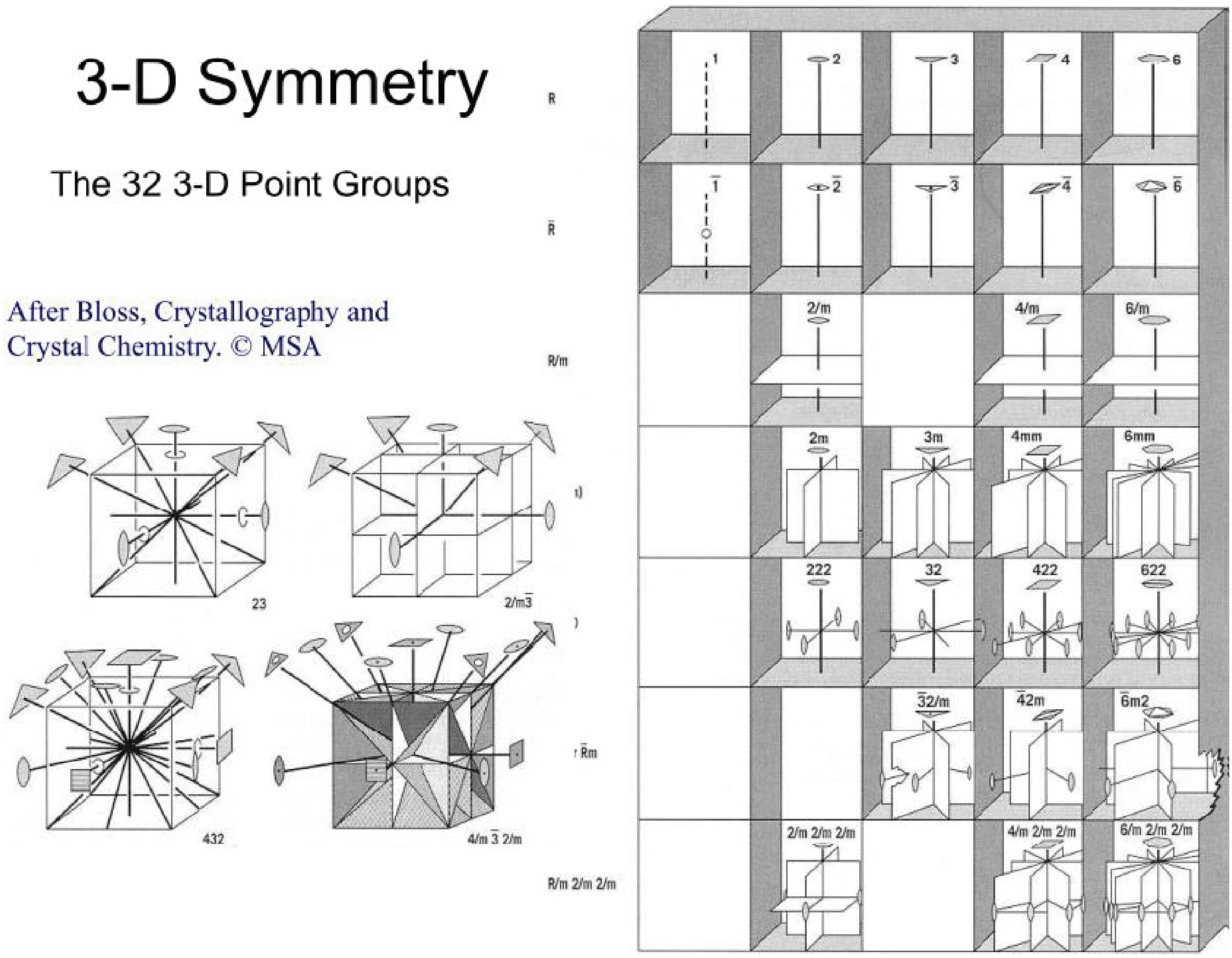
Operations include, (a) elements of symmetry; (b) translations; (c) glide planes; (d) screw axes.
Element: an operation located at a particular point in space.

Unit Cell: The smallest unit of a structure that can be indefinitely repeated to generate the whole structure.
Irrespective of the external form (Euhedral, Subhedral, or Anhedral) the properties and symmetry of every crystal can be condensed into the study of one single unit cell.



Regrouped by Crystal System (H & M symbol)

Crystal System	No Center	Center
Triclinic	1	$\bar{1}$
Monoclinic	2, $\bar{2}$ (= m)	2/m
Orthorhombic	222, 2mm	2/m 2/m 2/m
Tetragonal	4, $\bar{4}$, 422, 4mm, $\bar{4}$2m	4/m, 4/m 2/m 2/m
Hexagonal	3, 32, 3m 6, $\bar{6}$, 622, 6mm, $\bar{6}$2m	$\bar{3}$, $\bar{3}$ 2/m 6/m, 6/m 2/m 2/m
Isometric	23, 432, $\bar{4}$3m	2/m $\bar{3}$, 4/m $\bar{3}$ 2/m



Forms

1. **Pedion** (Monohedron): A single face comprising form

2. **Pinacoid**(Parallehedron): An open form made up of two parallel faces

3. **Dome** (Dihedron): Two non-parallel faces symmetric w.r.t a mirror plane (m).

4. **Sphenoid** (Dihedron): Two non-parallel faces symmetric w.r.t a 2-fold rotation axis

5. **Prism**: An open form composed of 3,4,6,8 or 12 faces, all of which are parallel to the same axis

6. **Pyramid**: An open form composed of 3,4,6,8 or 12 non parallel faces that meet at a point

7. **Dipyramid**: A closed form having 6, 8, 12, 16 or 24 faces.

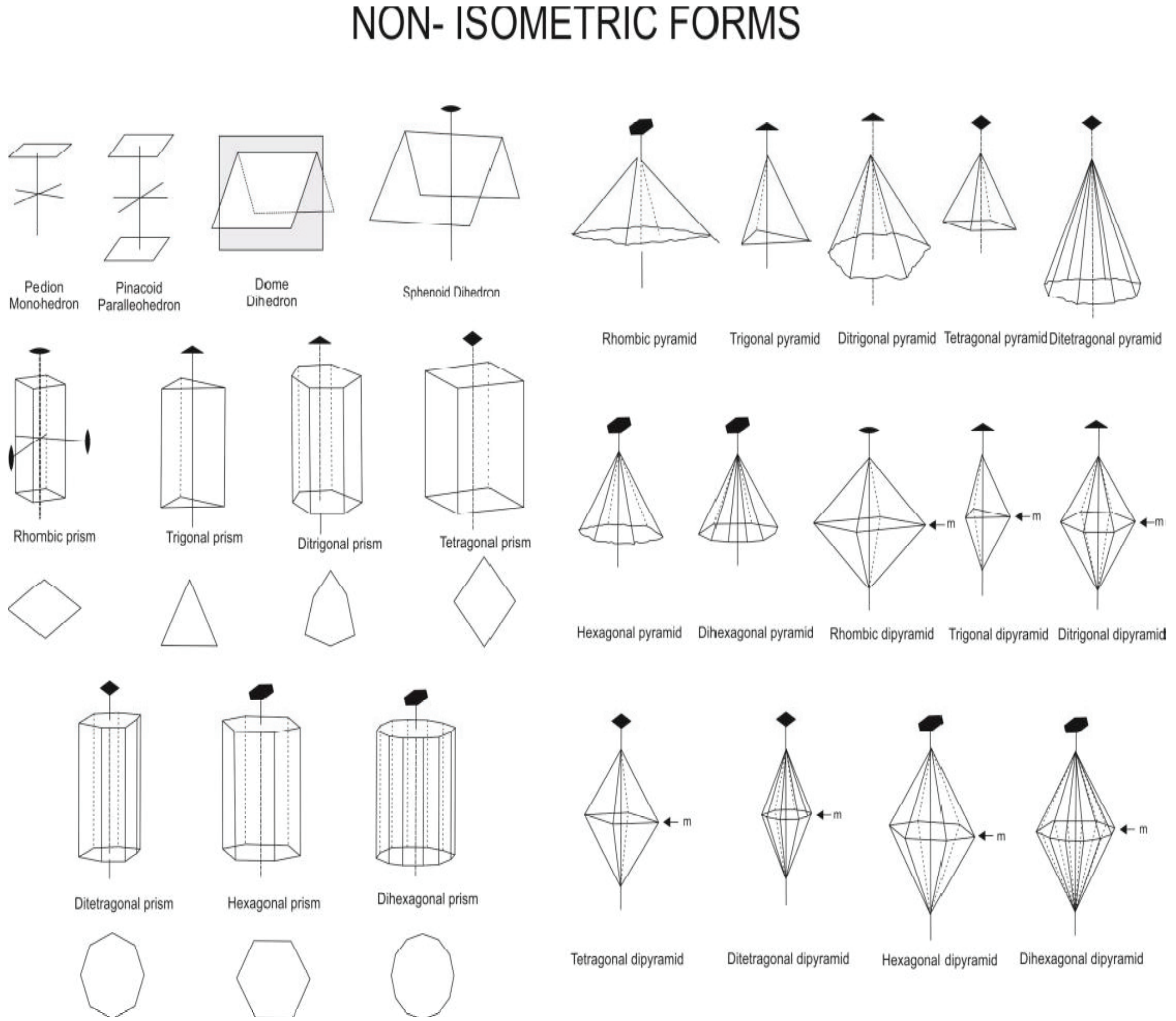
8. **Trapezohedron**: A closed form that has 6,8 or 12 faces in all, with 3,4 or 6 upper faces offset with 3,4 or 6 faces lower faces. These faces are the result of 3, 4 or 6 fold axis combined with perpendicular 2-fold axes.

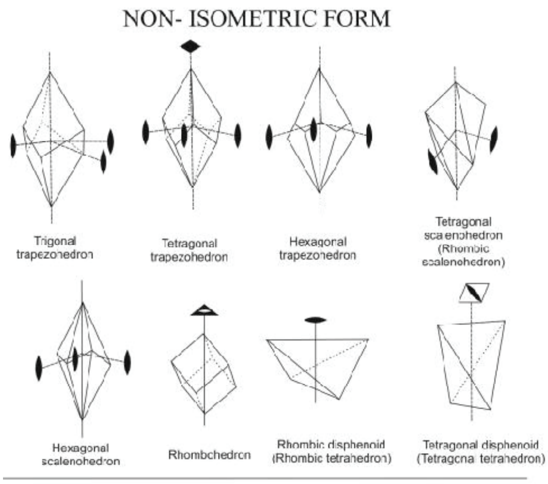
There is Isometric trapezohedron (tetragon-trisoctahedron) – 24 face form

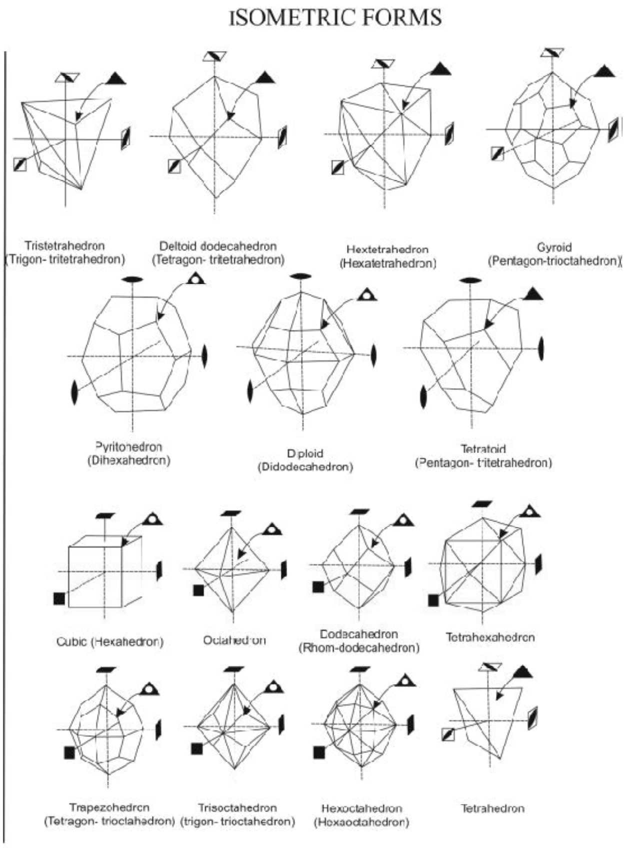
9. **Scalenohedron**: A closed form with 8 or 12 faces grouped in symmetrical pairs. In the tetragonal scalenohedron, (rhombic scalenohedron) pairs of upper faces are related by an axis of 4-fold rotoinverstion to pairs of lower faces. The 12 faces of hexagonal scalenohedron display three pairs of upper faces and three pairs of lower faces in alternating positions. The pairs are related by the center of symmetry; coexist with a 3-fold axis of rotoinverstion.

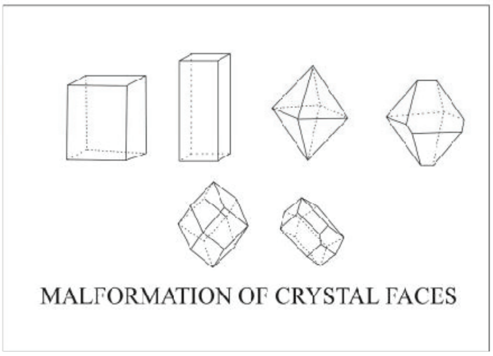
10. **Rhombohedron**: A closed form composed of six faces of which three faces at the top alternates with three faces at the bottom, the two sets of faces being offset by 60^o. Only seen in point groups.

11. **Disphenoid**: A closed form consisting of two upper faces that alternate with two lower faces, offset by 90^o.









Forms	*No. of Faces*	*Internationally recommended name (After FedrovInsituture)*
1. Cube	6	Hexahedron
2. Octahedron	8	Octahedron
3. Dodecahedron(rhombic)	12	Rhom-dodecahedron
4. Tetrahexahedron	24	Tetrahexahedron
5. Trapezohedron	24	Tetragon-Trioctahedron
6. Trisoctahedron	24	Tetragon-Trioctahedron
7. Hexaoctahedron	48	Hexaoctahedron
8. Tetrahedron	4	Tetrahedron
9. Tristetrahedron	12	Trigon-Tetrahedron
10. Deltoid dodecahedron	12	Tetragon-tritetrahedron
11. Hexatetrahedron	24	Hexatetrahedron
12. Gyroid	24	Pentagon-trioctahedron
13. Pyritohedron	12	Dihexahedron
14. Diploid	24	Di-dodecahedron
15. Tetartoid	12	Pentagon-tristetrahedron

Petrology

Petrology has come from two Greek words i.e. Petra means rock and logos means study.petrology is the study of rocks , which include their structure, texture,origin as well as classification.

It is again divided into two parts.

Petrography and petrogenesis.

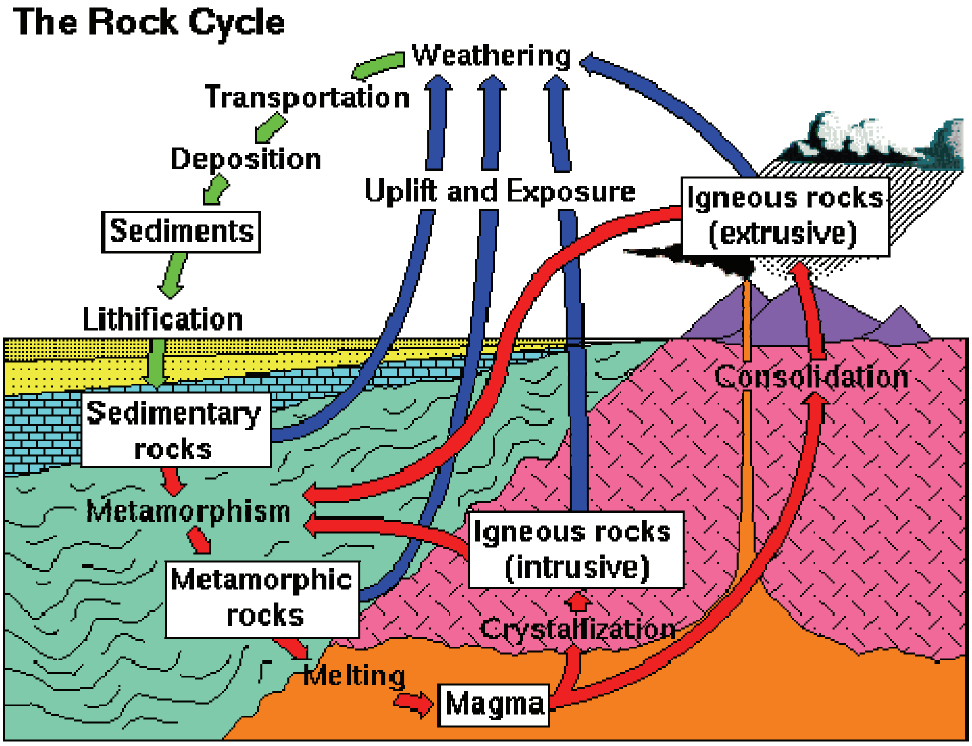
petrography deals with the classisification and description of rock where as petronenesis deals with the origin of rocks.There are mainly three types of rock found in Earth.

1.Igneous rock

2.sedimentary rock

3. Metamorphic rock

All these three rocks are genetically related to each other,which is shown in the rock cycle below:



Igneous rock:

Igneous rocks (from the Greek word for fire) form when hot, molten rock crystallizes and solidifies. The melt originates deep within the Earth near active plate boundaries or hot spots, then rises toward the surface. Igneous rocks are divided into two groups, intrusive or extrusive, depending upon where the molten rock solidifies.

IntrusiveIgneousRocks:

Intrusive, or plutonic, igneous rock forms when magma is trapped deep inside the Earth. Great globs of molten rock rise toward the surface. Some of the magma may feed volcanoes on the Earth's surface, but most remains trapped below, where it cools very slowly over many thousands or millions of years until it solidifies. Slow cooling means the individual mineral grains have a very long time to grow, so they grow to a relatively large size. Intrusive rocks have a coarse grained texture.

ExtrusiveRocks:

Extrusive, or volcanic, igneous rock is produced when magma exits and cools above (or very near) the Earth's surface. These are the rocks that form at erupting volcanoes and oozing fissures. The magma, called lava when molten rock erupts on the surface, cools and solidifies almost instantly when it is exposed to the relatively cool temperature of the atmosphere. Quick cooling means that mineral crystals don't have much time to grow, so these rocks have a very fine-grained or even glassy texture. Hot gas bubbles are often trapped in the quenched lava, forming a bubbly, vesicular texture.

Characteristics of Magma

Types

Types of magma are determined by chemical composition of the magma. Three general types are recognized, but we will look at other types later in the course:

1. ***Basaltic magma*** -- SiO_2 45-55 wt%, high in Fe, Mg, Ca, low in K, Na
2. ***Andesitic magma*** -- SiO_2 55-65 wt%, intermediate. in Fe, Mg, Ca, Na, K
3. ***Rhyolitic magma*** -- SiO_2 65-75%, low in Fe, Mg, Ca, high in K, Na

Gases in Magmas

At depth in the Earth nearly all magmas contain gas dissolved in the liquid, but the gas forms a separate vapor phase when pressure is decreased as magma rises toward the surface. This is similar to carbonated beverages which are bottled at high pressure. The high pressure keeps the gas in solution in the liquid, but when pressure is decreased, like when you open the can or bottle, the gas comes out of solution and forms a separate gas phase that you see as bubbles. Gas gives magmas their explosive character, because volume of gas expands as pressure is reduced. The composition of the gases in magma are:

- Mostly H_2O (water vapor) with some CO_2 (carbon dioxide)
- Minor amounts of Sulfur, Chlorine, and Fluorine gases

The amount of gas in a magma is also related to the chemical composition of the magma. Rhyolitic magmas usually have higher dissolved gas contents than basaltic magmas.

Temperature of Magmas

Temperature of magmas is difficult to measure (due to the danger involved), but laboratory measurement and limited field observation indicate that the eruption temperature of various magmas is as follows:

- Basaltic magma - 1000 to 1200^{o}C
- Andesitic magma - 800 to 1000^{o}C
- Rhyolitic magma - 650 to 800^{o}C.

Viscosity of Magmas

Viscosity is the resistance to flow (opposite of fluidity). Viscosity depends on primarily on the composition of the magma, and temperature.Higher SiO2 (silica) content magmas have higher viscosity than lower SiO2 content magmas (viscosity increases with increasing SiO2 concentration in the magma).Lower temperature magmas have higher viscosity than higher temperature magmas (viscosity decreases with increasing temperature of the magma).Thus, basaltic magmas tend to be fairly fluid (low viscosity), but their viscosity is still 10,000 to 100,0000 times more viscous than water. Rhyolitic magmas tend to have even higher viscosity, ranging between 1 million and 100 million times more viscous than water. (Note that solids, even though they appear solid have a viscosity, but it is very high, measured as trillions time the viscosity of water). Viscosity is an important property in determining the eruptive behavior of magmas.

Summary Table

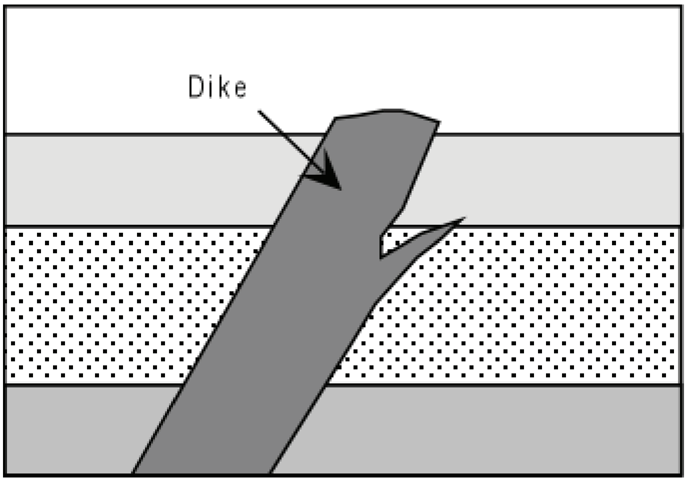
Magma Type	Solidified Rock	Chemical Composition	Temperature	Viscosity	Gas Content
Basaltic	Basalt	45-55 SiO_2 %, high in Fe, Mg, Ca, low in K, Na	1000 - 1200 ^{o}C	10 - 10^3 PaS	Low
Andesitic	Andesite	55-65 SiO_2 %, intermediate in Fe, Mg, Ca, Na, K	800 - 1000 ^{o}C	10^3 - 10^5 PaS	Intermediate
Rhyolitic	Rhyolite	65-75 SiO_2 %, low in Fe, Mg, Ca, high in K, Na.	650 - 800 ^{o}C	10^5 - 10^9 PaS	High

Plutonic (Intrusive) Igneous Rocks

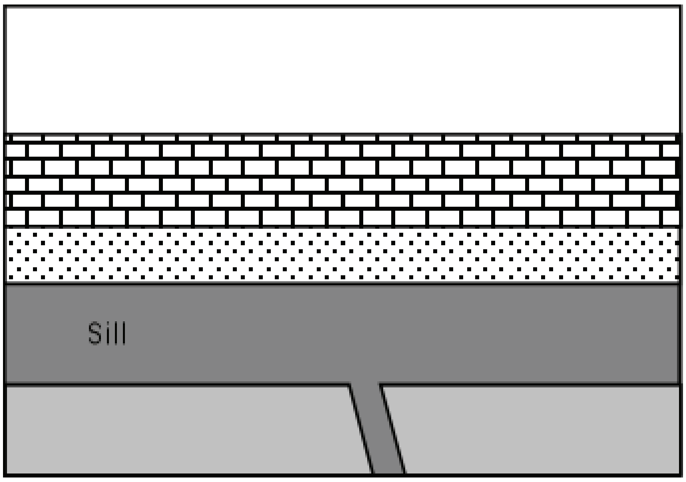
Hypabyssal Intrusions

Intrusions that intrude rocks at shallow levels of the crust are termed hypabyssal intrusions. Shallow generally refers to depths less than about 1 km. Hypabyssal intrusions always show sharp contact relations with the rocks that they intrude. Several types are found:

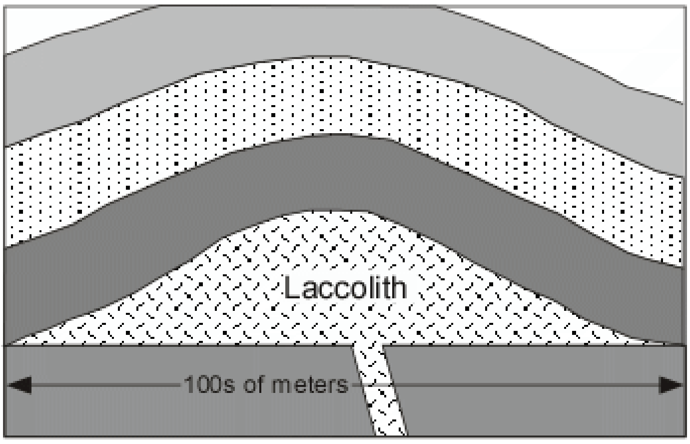
- **Dikes** are small (<20 m wide) shallow intrusions that show a discordant relationship to the rocks in which they intrude. Discordant means that they cut across preexisting structures. They may occur as isolated bodies or may occur as swarms of dikes emanating from a large intrusive body at depth.



- **Sills** are also small (<50 m thick) shallow intrusions that show a concordant relationship with the rocks that they intrude. Sills usually are fed by dikes, but these may not be exposed in the field.



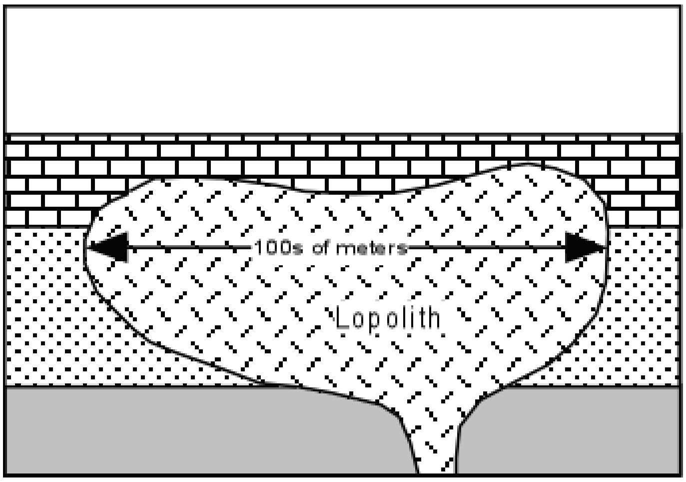
- **Laccoliths** are somewhat large intrusions that result in uplift and folding of the preexisting rocks above the intrusion. They are also concordant types of intrusions.



Plutons

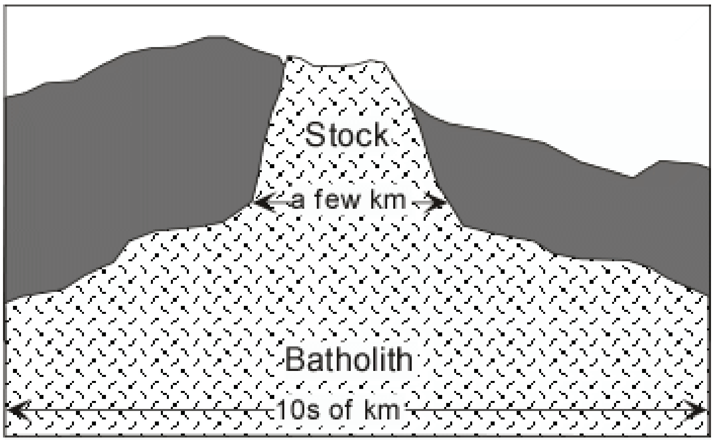
Plutons are generally much larger intrusive bodies that have intruded much deeper in the crust. Although they may show sharp contacts with the surrounding rocks into which they intruded, at deeper levels in the crust the contacts are often gradational.

- **Lopoliths** are relatively small plutons that usually show a concave downward upper surface. This shape may have resulted from the reduction in volume that occurs when magmas crystallize, with the weight of the overlying rocks causing collapse of into the space once occupied by the magma when it had a larger volume as a liquid.



- **Batholiths** are very large intrusive bodies, usually so large that there bottoms are rarely exposed. Sometimes they are composed of several smaller intrusions.

- **Stocks** are smaller bodies that are likely fed from deeper level batholiths. Stocks may have been feeders for volcanic eruptions, but because large amounts of erosion are required to expose a stock or batholith, the associated volcanic rocks are rarely exposed.



Volcanic (Extrusive) Igneous Rocks

Volcanic Eruptions

- In general, magmas that are generated deep within the Earth begin to rise because they are less dense than the surrounding solid rocks.
- As they rise they may encounter a depth or pressure where the dissolved gas no longer can be held in solution in the magma, and the gas begins to form a separate phase (i.e. it makes bubbles just like in a bottle of carbonated beverage when the pressure is reduced).

- When a gas bubble forms, it will also continue to grow in size as pressure is reduced and more of the gas comes out of solution. In other words, the gas bubbles begin to expand.
- If the liquid part of the magma has a low viscosity, then the gas can expand relatively easily. When the magma reaches the surface, the gas bubble will simply burst, the gas will easily expand to atmospheric pressure, and a non-explosive eruption will occur, usually as a lava flow (***Lava*** is the name we give to a magma on the surface of the

Earth).

- If the liquid part of the magma has a high viscosity, then the gas will not be able to expand easily. Thus, pressure will build inside the gas bubble(s). When the magma reaches the surface, the gas bubbles will have a high pressure inside, which will cause them to burst explosively on reaching atmospheric pressure. This will cause an explosive volcanic eruption.

Tephra and Pyroclastic Rocks

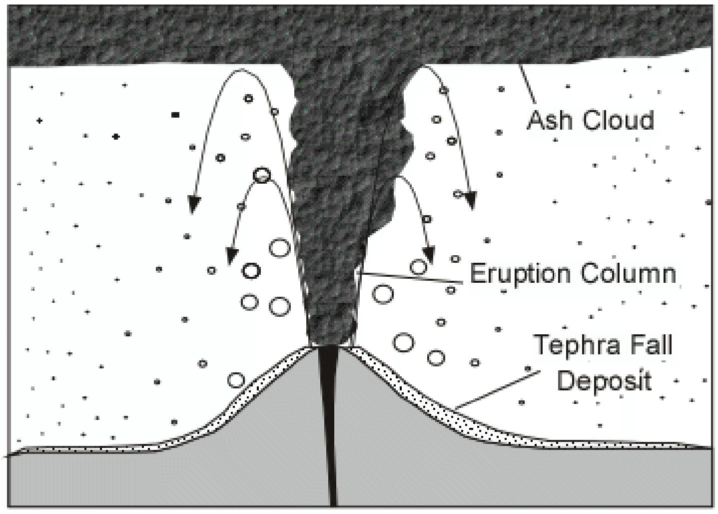
Average Particle Size (mm)	Unconsolidated Material (Tephra)	Pyroclastic Rock
>64	Bombs or Blocks	Agglomerate
2 - 64	Lapilli	Lapilli Tuff
<2	Ash	Ash Tuff

- ***Blocks*** are angular fragments that were solid when ejected.

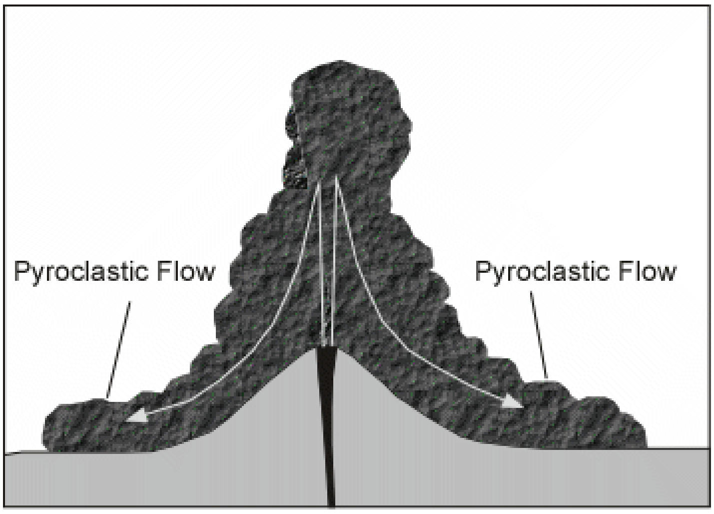
- ***Bombs*** have an aerodynamic shape indicating they were liquid when ejected.

- Bombs and lapilli that consist mostly of gas bubbles (***vesicles***) result in a low density highly vesicular rock fragment called ***pumice***.

- Clouds of gas and tephra that rise above a volcano produce an eruption column that can rise up to 45 km into the atmosphere. Eventually the tephra in the eruption column will be picked up by the wind, carried for some distance, and then fall back to the surface as a tephra fall or ash fall.



- If the eruption column collapses a pyroclastic flow will occur, wherein gas and tephra rush down the flanks of the volcano at high speed. This is the most dangerous type of volcanic eruption. The deposits that are produced are called ignimbrites if they contain pumice or pyroclastic flow deposits if they contain non-vesicular blocks.



Nonexplosive Eruptions

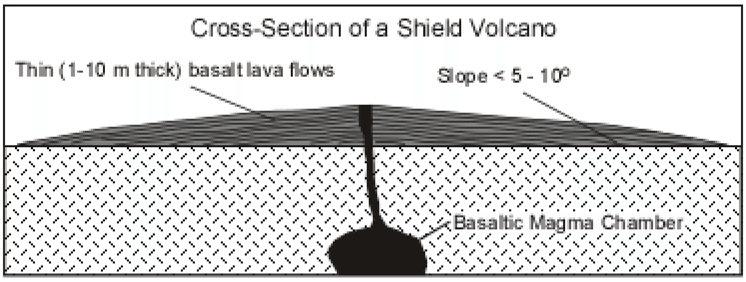
Non explosive eruptions are favored by low gas content and low viscosity magmas (basaltic to andesitic magmas).

- If the viscosity is low, nonexplosive eruptions usually begin with fire fountains due to release of dissolved gases.
- Lava flows are produced on the surface, and these run like liquids down slope, along the lowest areas they can find.
- Lava flows produced by eruptions under water are called ***pillow lavas***.
- If the viscosity is high, but the gas content is low, then the lava will pile up over the vent to produce a ***lava dome*** or ***volcanic dome.***

Volcanic Landforms

Shield Volcanoes

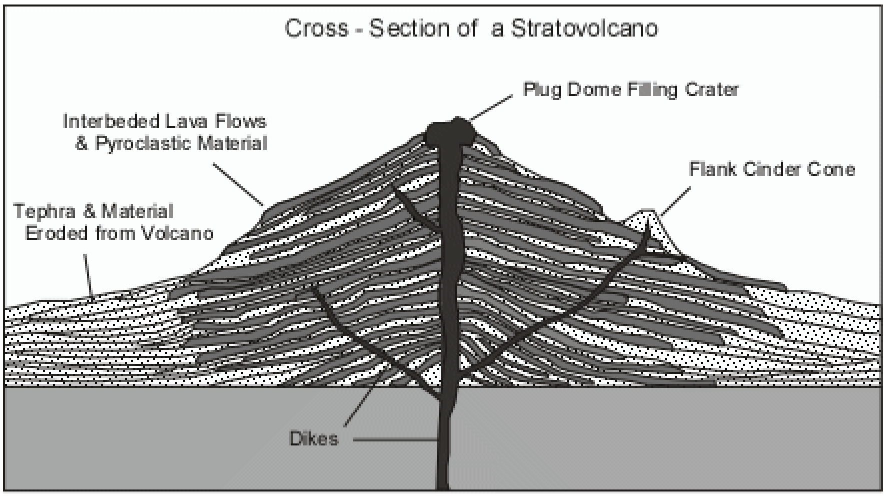
- A shield volcano is characterized by gentle upper slopes (about 5^o) and somewhat steeper lower slopes (about 10^o).



- Shield volcanoes are composed almost entirely of thin lava flows built up over a central vent.
- Most shields are formed by low viscosity basaltic magma that flows easily down slope away form a summit vent.
- The low viscosity of the magma allows the lava to travel down slope on a gentle slope, but as it cools and its viscosity increases, its thickness builds up on the lower slopes giving a somewhat steeper lower slope.
- Most shield volcanoes have a roughly circular or oval shape in map view.
- Very little pyroclastic material is found within a shield volcano, except near the eruptive vents, where small amounts of pyroclastic material accumulate as a result of

fire fountaining events.

Stratovolcanoes (also called **Composite Volcanoes**)

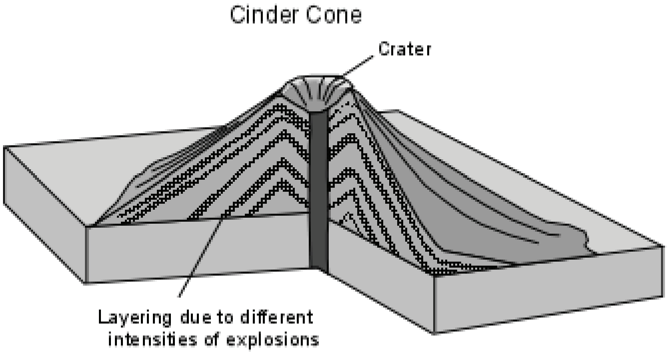


- Have steeper slopes than shields, with slopes of 6 - 10° low on the flanks to 30° near the summit.
- Steep slope near the summit result from thick, short viscous lava flows that don't travel far from the vent.
- The gentler slopes near the base are due to accumulations of material eroded from the volcano and to the accumulation of pyroclastic material.
- Stratovolcanoes show inter-layering of lava flows and pyroclastic material, which is why they are sometimes called composite volcanoes. Pyroclastic material can make up over 50% of the volume of a stratovolcano.
- Lavas and pyroclastics are usually andesitic to rhyolitic in composition.
- Due to the higher viscosity of magmas erupted from these volcanoes, they are usually more explosive than shield volcanoes.
- Stratovolcanoes sometimes have a crater at the summit, that is formed by explosive ejection of material from a central vent. Sometimes the craters have been filled in by lava flows or lava domes, sometimes they are filled with glacial ice, and less commonly they are filled with water.
- Long periods of repose (times of inactivity) lasting for hundreds to thousands of years, make this type of volcano particularly dangerous, since many times they have shown no historic activity, and people are reluctant to heed warnings about possible eruptions.

Tephra Cones (also called **Cinder Cones**)

- Tephra cones are small volume cones consisting predominantly of tephra that result from strombolian eruptions. They usually consist of basaltic to andesitic material.
- They are actually fall deposits that are built surrounding the eruptive vent.

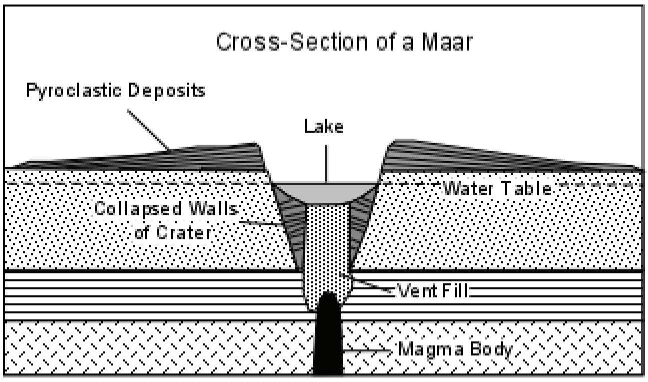
- Slopes of the cones are controlled by the angle of repose (angle of stable slope for loose unconsolidated material) and are usually between about 25 and 35°.
- They show an internal layered structure due to varying intensities of the explosions that deposit different sizes of pyroclastics.



- On young cones, a depression at the top of the cone, called a crater, is evident, and represents the area above the vent from which material was explosively ejected. Craters are usually eroded away on older cones.
- If lava flows are emitted from tephra cones, they are usually emitted from vents on the flank or near the base of the cone during the later stages of eruption.
- Cinder and tephra cones usually occur around summit vents and flank vents of stratovolcanoes.
- An excellent example of cinder cone is Parícutin Volcano in Mexico. This volcano was born in a farmers corn field in 1943 and erupted for the next 9 years. Lava flows erupted from the base of the cone eventually covered two towns.
- Cinder cones often occur in groups, where tens to hundreds of cones are found in one area

Maars

- Maars result from phreatic or phreatomagmatic activity, wherein magma heats up water in the groundwater system, pressure builds as the water to turns to steam, and then the water and preexisting rock (and some new magma if the eruption is phreatomagmatic) are blasted out of the ground to form a tephra cone with gentle slopes.

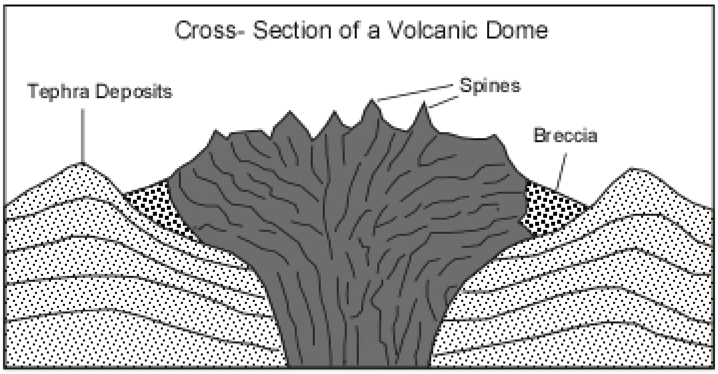


Parts of the crater walls eventually collapse back into the crater, the vent is filled with loose material, and, if the crater still is deeper than the water table, the crater fills with water to form a lake, the lake level coinciding with the water table.

Lava Domes (also called **Volcanic Domes**)

- Volcanic Domes result from the extrusion of highly viscous, gas poor andesitic and rhyolitic lava. Since the viscosity is so high, the lava does not flow away from the vent, but instead piles up over the vent.

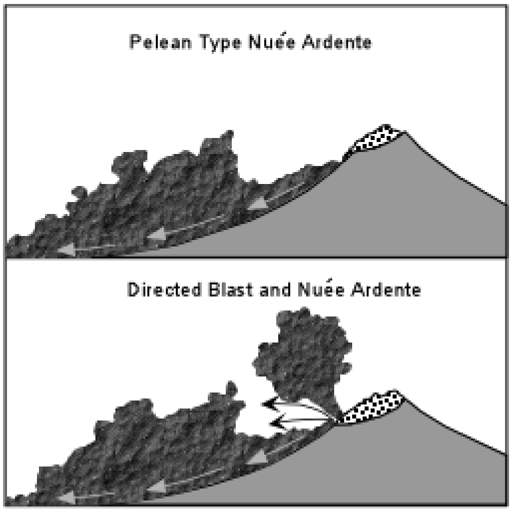
- Blocks of nearly solid lava break off the outer surface of the dome and roll done its flanks to form a breccia around the margins of domes.
- The surface of volcanic domes are generally very rough, with numerous spines that have been pushed up by the magma from below.



- Most dome eruptions are preceded by explosive eruptions of more gas rich magma, producing a tephra cone into which the dome is extruded.

- Volcanic domes can be extremely dangerous. because they form unstable slopes that may collapse to expose gas-rich viscous magma to atmospheric pressure. This can result in lateral blasts or Pelean type pyroclastic flow (nuee ardent) eruptions.

Pyroclastic Flows Generated by Dome Collapse



Craters and Calderas

- Craters are circular depressions, usually less than 1 km in diameter, that form as a result of explosions that emit gases and tephra.
- Calderas are much larger depressions, circular to elliptical in shape, with diameters ranging from 1 km to 50 km. Calderas form as a result of collapse of a volcanic structure. The collapse results from evacuation of the underlying magma chamber.
- In shield volcanoes, like in Hawaii, the evacuation of the magma chamber is a slow drawn out processes, wherein magma is withdrawn to erupt on from the rift zones on the flanks.
- In stratovolcanoes the collapse and formation of a caldera results from rapid evacuation of the underlying magma chamber by voluminous explosive eruptions that form extensive fall deposits and pyroclastic flows.
- Calderas are often enclosed depressions that collect rain water and snow melt, and thus lakes often form within a caldera.

Plateau Basalts or **Flood Basalts**

- Plateau or Flood basalts are extremely large volume outpourings of low viscosity basaltic magma from fissure vents. The basalts spread huge areas of relatively low slope and build up plateaus.
- The only historic example occurred in Iceland in 1783, where the Laki basalt erupted from a 32 km long fissure and covered an area of 588 km^2 with 12 km^3 of lava. As a

result of this eruption, homes were destroyed, livestock were killed, and crops were destroyed, resulting in a famine that killed 9336 people.

Textures of Igneous Rocks

The main factor that determines the texture of an igneous rock is the ***cooling rate*** (dT/dt)

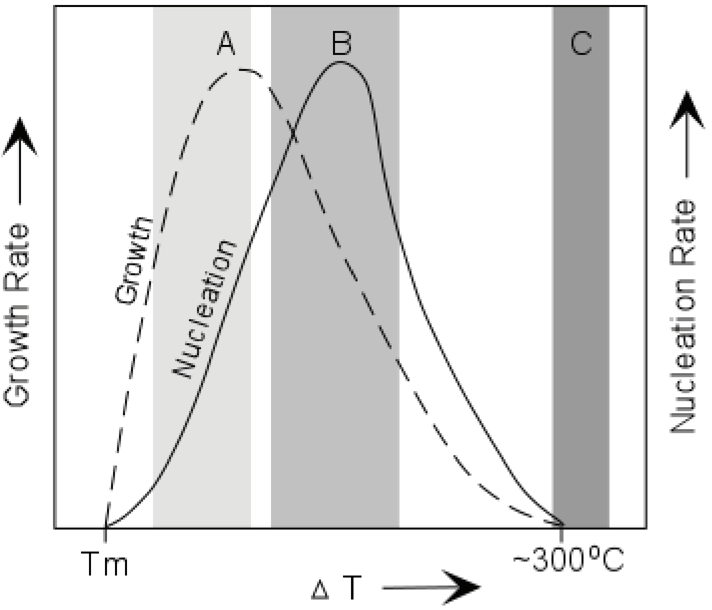
Other factors involved are:

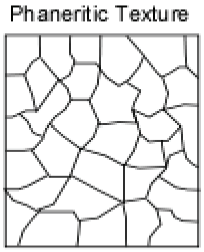
- The diffusion rate - the rate at which atoms or molecules can move (diffuse) through the liquid.
- The rate of nucleation of new crystals - the rate at which enough of the chemical constituents of a crystal can come together in one place without dissolving.
- The rate of growth of crystals - the rate at which new constituents can arrive at the surface of the growing crystal. This depends largely on the diffusion rate of the molecules of concern.

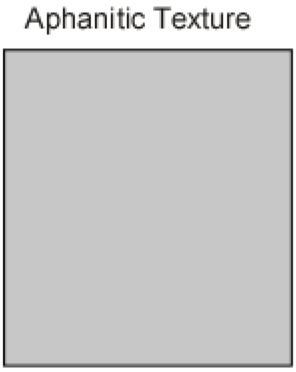
In order for a crystal to form in a magma enough of the chemical constituents that will make up the crystal must be at the same place at the same time to form a ***nucleus*** of the crystal. Once a nucleus forms, the chemical constituents must diffuse through the liquid to arrive at the surface of the growing crystal. The crystal can then grow until it runs into other crystals or the supply of chemical constituents is cut off.

All of these rates are strongly dependent on the temperature of the system. First, nucleation and growth cannot occur until temperatures are below the temperature at which equilibrium crystallization begins. Shown below are hypothetical nucleation and growth rate curves based on experiments in simple systems. Note that the rate of crystal growth and nucleation depends on how long the magma resides at a specified degree of undercooling ($\Delta T = T_m - T$), and thus the rate at which temperature is lowered below the the crystallization temperature. Three cases are shown.

1. For small degrees of undercooling (region A in the figure to the right) the nucleation rate will be low and the growth rate moderate. A few crystals will form and grow at a moderate rate until they run into each other. Because there are few nuclei, the crystals will be able to grow to relatively large size, and a coarse grained texture will result. This would be called a ***phaneritic texture***.



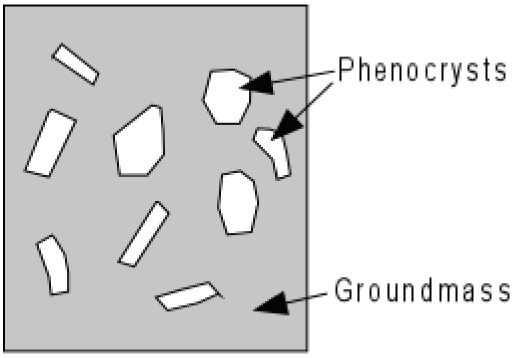




2. At larger degrees of undercooling, the nucleation rate will be high and the growth rate also high. This will result in many crystals all growing rapidly, but because there are so many crystals, they will run into each other before they have time to grow and the resulting texture will be a fine grained texture. If the size of the grains are so small that crystals cannot be distinguished with a handlens, the texture is said to be ***aphanitic***.

3. At high degrees of undercooling, both the growth rate and nucleation rate will be low. Thus few crystals will form and they will not grow to any large size. The resulting texture will be glassy, with a few tiny crystals called microlites. A completely glassy texture is called ***holohyaline texture***.

Two stages of cooling, i.e. slow cooling to grow a few large crystals, followed by rapid cooling to grow many smaller crystals could result in a ***porphyritic texture***, a texture with two or more distinct sizes of grains. Single stage cooling can also produce a porphyritic texture. In a porphyritic texture, the larger grains are called ***phenocrysts*** and the material surrounding the the phenocrysts is called ***groundmass*** or ***matrix***



In a rock with a phaneritic texture, where all grains are about the same size, we use the grain size ranges shown to the right to describe the texture:

<1 mm	fine grained
1 - 5 mm	medium grained
5 - 3 cm	coarse grained
> 3 cm	very coarse grained

In a rock with a porphyritic texture, we use the above table to define the grain size of the groundmass or matrix, and this table to describe the phenocrysts:

0.03 - 0.3 mm	microphenocrysts
0.3 - 5 mm	phenocrysts
> 5 mm	megaphenocrysts

Another aspect of texture, particularly in medium to coarse grained rocks is referred to as fabric. ***Fabric*** refers to the mutual relationship between the grains. Three types of fabric are commonly referred to:

1. If most of the grains are ***euhedral*** - that is they are bounded by well-formed crystal

faces. The fabric is said to be ***idomorphic granular***.

2. If most of the grains are ***subhedral*** - that is they bounded by only a few well-formed crystal faces, the fabric is said to be ***hypidiomorphic granular***.
3. If most of the grains are ***anhedral*** - that is they are generally not bounded by crystal faces, the fabric is said to be ***allotriomorphic granular***.

If the grains have particularly descriptive shapes, then it is essential to describe the individual grains. Some common grain shapes are:

- *Tabular* - a term used to describe grains with rectangular tablet shapes.
- *Equant* - a term used to describe grains that have all of their boundaries of approximately equal length.
- *Fibrous* - a term used to describe grains that occur as long fibers.
- *Acicular* - a term used to describe grains that occur as long, slender crystals.
- *Prismatic* - a term used to describe grains that show an abundance of prism faces.

Other terms may apply to certain situations and should be noted if found in a rock.

- *Vesicular* - if the rock contains numerous holes that were once occupied by a gas phase, then this term is added to the textural description of the rock.
- *Glomeroporphyritic* - if phenocrysts are found to occur as clusters of crystals, then the rock should be described as glomeroporphyritic instead of porphyritic.
- *Amygdular* - if vesicles have been filled with material (usually calcite, chalcedonay, or quartz, then the term amygdular should be added to the textural description of the rock. An amygdule is defined as a refilled vesicle.
- *Pumiceous* - if vesicles are so abundant that they make up over 50% of the rock and the rock has a density less than 1 (i.e. it would float in water), then the rock is pumiceous.
- *Scoraceous*- if vesicles are so abundant that they make up over 50% of the rock and the rock has a density greater than 1, then the rock is said to be scoraceous.
- *Graphic* - a texture consisting of intergrowths of quartz and alkali feldspar wherein the orientation of the quartz grains resembles cuneiform writing. This texture is most commonly observed in pegmatites.
- *Spherulitic* - a texture commonly found in glassy rhyolites wherein spherical intergrowths of radiating quartz and feldspar replace glass as a result of devitrification.
- *Obicular* - a texture usually restricted to coarser grained rocks that consists of concentrically banded spheres wherein the bands consist of alternating light colored and dark colored minerals.

Other textures that may be evident on microscopic examination of igneous rocks are as follows:

- *Myrmekitic texture* - an intergrowth of quartz and plagioclase that shows small wormlike bodies of quartz enclosed in plagioclase. This texture is found in granites.

- *Ophitic texture* - laths of plagioclase in a coarse grained matrix of pyroxene crystals, wherein the plagioclase is totally surrounded by pyroxene grains. This texture is common in diabases and gabbros.

- *Subophitic texture* - similar to ophitic texture wherein the plagioclase grains are not completely enclosed in a matrix of pyroxene grains.

- *Poikilitic texture* - smaller grains of one mineral are completely enclosed in large, optically continuous grains of another mineral.

- *Intergranular texture* - a texture in which the angular interstices between plagioclase grains are occupied by grains of ferromagnesium minerals such as olivine, pyroxene, or iron titanium oxides.

- *Intersertal texture* - a texture similar to intergranular texture except that the interstices between plagioclase grains are occupied by glass or cryptocrystalline material.

- *Hyaloophitic texture* - a texture similar to ophitic texture except that glass completely surrounds the plagioclase laths.

- *Hyalopilitic texture* - a texture wherein microlites of plagioclase are more abundant than groundmass, and the groundmass consists of glass which occupies the tiny interstices between plagioclase grains.

- *Trachytic texture* - a texture wherein plagioclase grains show a preferred orientation due to flowage, and the interstices between plagioclase grains are occupied by glass or cryptocrystalline material.

- *Coronas or reaction rims* - often times reaction rims or coronas surround individual crystals as a result of the crystal becoming unstable and reacting with its surrounding crystals or melt. If such rims are present on crystals they should be noted in the textural description.

- *Patchy zoning* - This sometimes occurs in plagioclase crystals where irregularly shaped patches of the crystal show different compositions as evidenced by going extinct at angles different from other zones in the crystal.

- *Oscillatory zoning* - This sometimes occurs in plagioclase grains wherein concentric zones around the grain show thin zones of different composition as evidenced by extinction phenomena.

- *Moth eaten texture* (also called *sieve texture*)- This sometimes occurs in plagioclase wherein individual plagioclase grains show an abundance of glassy inclusions.

- *Perthitic texture* - Exsolution lamellae of albite occurring in orthoclase or microcline.

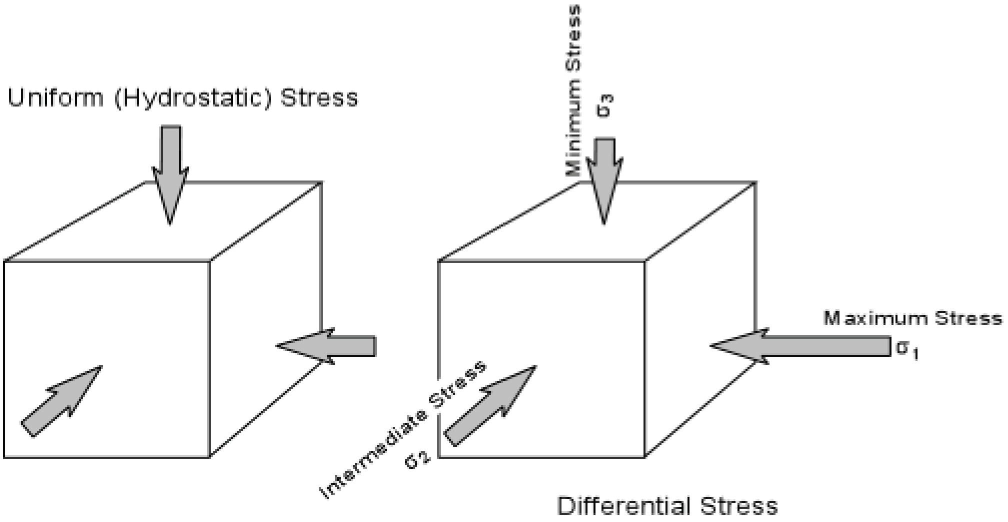
Metamorphic rocks exhibit a variety of textures. These can range from textures similar to the original protolith at low grades of metamorphism, to textures that are purely produced during metamorphism and leave the rock with little resemblance to the original protolith. Textural features of metamorphic rocks have been discussed in the previous lecture. Here, we concentrate on the development of foliation, one of the most common purely metamorphic textures, and on the processes involved in forming compositional layering commonly observed in metamorphic rocks.

Foliation

Foliation is defined as a pervasive planar structure that results from the nearly parallel alignment of sheet silicate minerals and/or compositional and mineralogical layering in the rock. Most foliation is caused by the preferred orientation of phylosilicates, like clay minerals, micas, and chlorite. Preferred orientation develops as a result of non-hydrostatic or differential stress acting on the rock (also called deviatoric stress). We here review the differences between hydrostatic and differential stress.

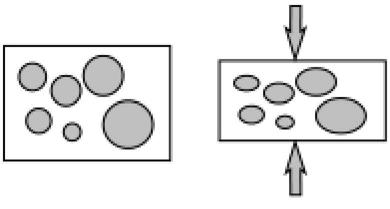
Stress and Preferred Orientation

Pressure increases with depth of burial, thus, both pressure and temperature will vary with depth in the Earth. Pressure is defined as a force acting equally from all directions. It is a type of stress, called hydrostatic stress or uniform stress. If the stress is not equal from all directions, then the stress is called a differential stress. Normally geologists talk about stress as compressional stress. Thus, if a differential stress is acting on the rock, the direction along which the maximum principal stress acts is called □1, the minimum principal stress is called □3, and the intermediate principal stress direction is called □2. Note that extensional stress would act along the direction of minimum principal stress.

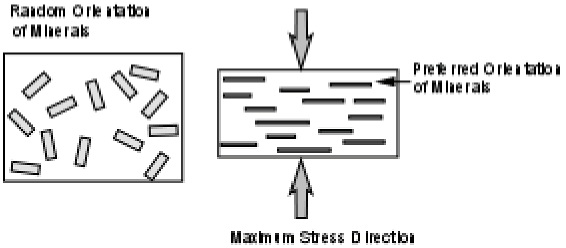


If differential stress is present during metamorphism, it can have a profound effect on the texture of the rock.

- Rounded grains can become flattened in the direction of maximum compressional stress.



- Minerals that crystallize or grow in the differential stress field may develop a preferred orientation. Sheet silicates and minerals that have an elongated habit will grow with their sheets or direction of elongation orientated perpendicular to the direction of maximum stress.

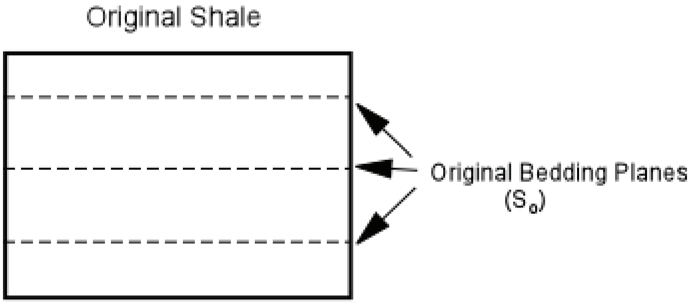


This is because growth of such minerals is easier along directions parallel to sheets, or along the direction of elongation and thus will grow along σ_3 or σ_2, perpendicular to σ_1.

Since most phyllosilicates are aluminous minerals, aluminous (pelitic) rocks like shales, generally develop a foliation as the result of metamorphism in a differential stress field.

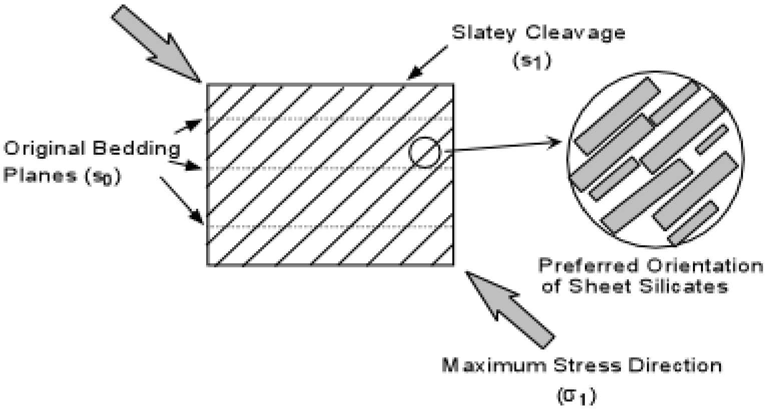
Example - metamorphism of a shale (made up initially of clay minerals and quartz)

Shales have fissility that is caused by the preferred orientation of clay minerals with their {001} planes orientated parallel to bedding. Metamorphic petrologists and structural geologists refer to the original bedding surface as S0.

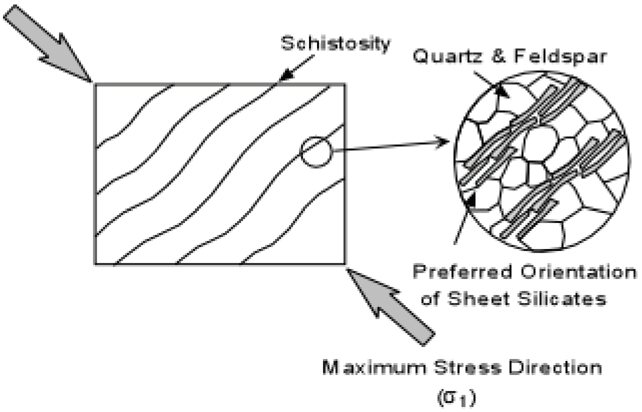


- ***Slate*** Slates form at low metamorphic grade by the growth of fine grained chlorite and clay minerals. The preferred orientation of these sheet silicates causes the rock to easily break planes parallel to the sheet silicates, causing a ***slatey cleavage.***

Note that in the case shown here, the maximum principle stress is oriented at an angle to the original bedding planes so that the slatey cleavage develops at an angle to the original bedding. The foliation or surface produced by this deformation is referred to S_1.

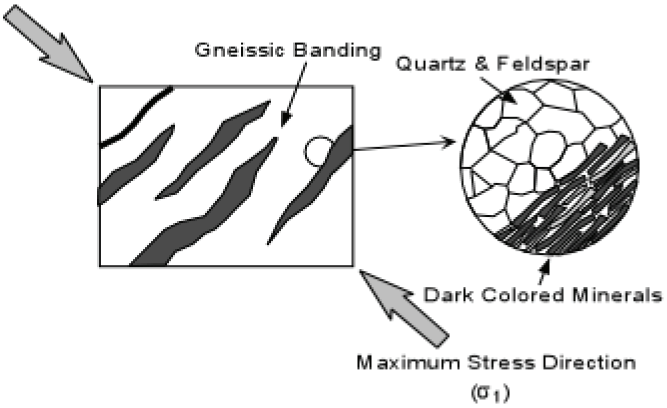


Schist - The size of the mineral grains tends to enlarge with increasing grade of metamorphism. Eventually the rock develops a near planar foliation caused by the preferred orientation of sheet silicates (mainly biotite and muscovite). Quartz and feldspar grains, however show no preferred orientation. The irregular planar foliation at this stage is called schistosity

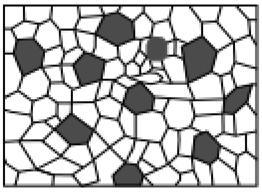


- ***Gneiss*** As metamorphic grade increases, the sheet silicates become unstable and dark colored minerals like hornblende and pyroxene start to grow.

These dark colored minerals tend to become segregated into distinct bands through the rock (this process is called metamorphic differentiation), giving the rock a gneissic banding. Because the dark colored minerals tend to form elongated crystals, rather than sheet- like crystals, they still have a preferred orientation with their long directions perpendicular to the maximum differential stress.



Granulite - At the highest grades of metamorphism most of the hydrous minerals and sheet silicates become unstable and thus there are few minerals present that would show a preferred orientation. The resulting rock will have a granulitic texture that is similar to a phaneritic texture in igneous rocks.

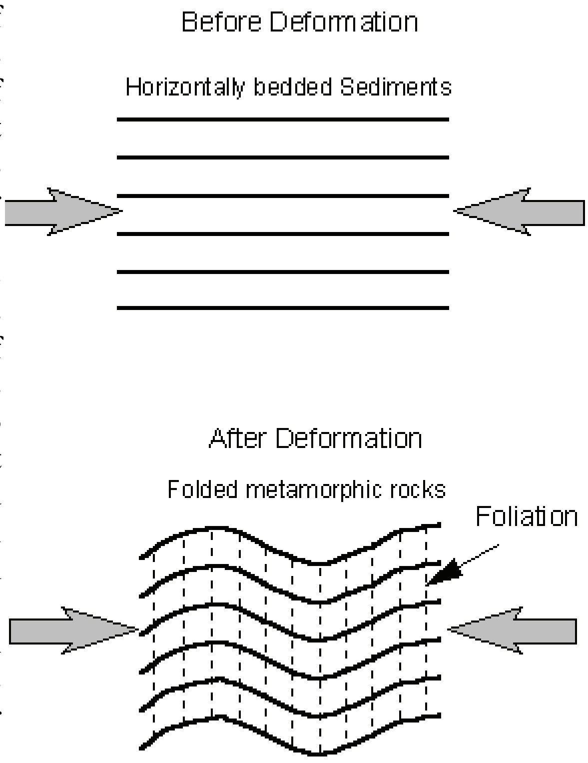


In general, the grain size of metamorphic rocks tends to increase with increasing grade of metamorphism, as seen in the progression form fine grained shales to coarser (but still fine) grained slates, to coarser grained schists and gneisses.

Metamorphism and Deformation

Most regionally metamorphosed rocks (at least those that eventually get exposed at the Earth's surface) are metamorphosed during deformational events. Since deformation involves the application of differential stress, the textures that develop in metamorphic rocks reflect the mode of deformation, and foliations or slatey cleavage that develop during metamorphism reflect the deformational mode and are part of the deformational structures.

The deformation involved in the formation of fold-thrust mountain belts generally involves compressional stresses. The result of compressional stress acting on rocks that behave in a ductile manner (ductile behavior is favored by higher temperature, higher confining stress [pressure] and low strain rates) is the folding of rocks. Original bedding is folded into a series of anticlines and synclines with fold axes perpendicular to the direction of maximum compressional stress. These folds can vary in their scale from centimeters to several kilometers between hinges. Note that since the axial planes are oriented perpendicular to the maximum compressional stress direction, slatey cleavage or foliation should also develop along these directions. Thus, slatey cleavage or foliation is often seen to be parallel to the axial planes of folds, and is sometimes referred to axial plane cleavage or foliation.



Sedimentary Petrology

Sedimentary petrology is the study of their occurrence, composition, texture, and other overall characteristics, while sedimentology emphasizes the processes by which sediments are transported and deposited.

ivers, oceans, winds, and rain runoff all have the ability to carry the particles washed off of oding rocks. Such material, called detritus, consists of fragments of rocks and minerals. When e energy of the transporting current is not strong enough to carry these particles, the particles op out in the process of sedimentation. This type of sedimentary deposition is referred to clastic sedimentation. Another type of sedimentary deposition occurs when material is ssolved in water, and chemically precipitates from the water. This type of sedimentation is ferred to as chemical sedimentation. A third process can occur, wherein living organisms tract ions dissolved in water to make such things as shells and bones. This type of dimentation is called biochemical sedimentation. The accumulation of plant matter, such as at e bottom of a swamp, is referred to as organic sedimentation. Thus, there are 4 major types of dimentary rocks: Clastic Sedimentary Rocks, Chemical Sedimentary Rocks, Biochemical dimentary Rocks, and Organic Sedimentary Rocks.

Clastic Sediments and Sedimentary Rocks

The formation of a clastic sediment and sedimentary rocks involves five processes:

1. ***Weathering*** - The first step is transforming solid rock into smaller fragments or

dissolved ions by physical and chemical weathering as discussed in the last lecture.

4. Erosion - Erosion is actually many processes which act together to lower the surface of the earth. In terms of producing sediment, erosion begins the transportation process by moving the weathered products from their original location. This can take place by gravity (massmovement events like landslides or rock falls), by running water. by wind, or by moving ice. Erosion overlaps with transportation.
5. Transportation - Sediment can be transported by sliding down slopes, being picked up by the wind, or by being carried by running water in streams, rivers, or ocean currents. The distance the sediment is transported and the energy of the transporting medium all leave clues in the final sediment that tell us something about the mode of transportation.

6. Deposition - Sediment is deposited when the energy of the transporting medium becomes too low to continue the transport process. In other words, if the velocity of the transporting medium becomes too low to transport sediment, the sediment will fall out and become deposited. The final sediment thus reflects the energy of the transporting medium.
7. ***Lithification (Diagenesis)*** - Lithification is the process that turns sediment into rock. The first stage of the process is compaction. Compaction occurs as the weight of the overlying material increases. Compaction forces the grains closer together, reducing pore space and eliminating some of the contained water. Some of this water may carry mineral components in solution, and these constituents may later precipitate as new minerals in the pore spaces. This causes cementation, which will then start to bind the individual particles together.

Classification - Clastic sedimentary particles and sedimentary rocks are classified in terms of grain size and shape, among other factors.

Name of Particle	Size Range	Loose Sediment	Consolidated Rock
Boulder	>256 mm	Gravel	Conglomerate or Breccia (depends on rounding)
Cobble	64 - 256 mm	Gravel	
Pebble	2 - 64 mm	Gravel	
Sand	1/16 - 2mm	Sand	Sandstone
Silt	1/256 - 1/16 mm	Silt	Siltstone
Clay	<1/256 mm	Clay	Claystone, mudstone, and shale

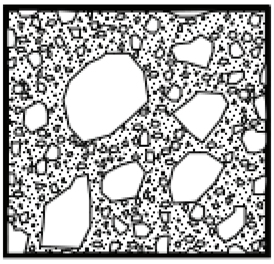
n general, the coarser sediment gets left behind by the transportation process. Thus, coarse ediment is usually found closer to its source and fine grained sediment is found farther from the ource.

extures of Clastic Sedimentary Rocks

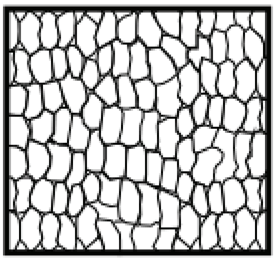
Vhen sediment is transported and deposited, it leaves clues to the mode of transport and eposition. For example, if the mode of transport is by sliding down a slope, the deposits that esult are generally chaotic in nature, and show a wide variety of particle sizes. Grain size and e interrelationship between grains gives the resulting sediment texture. Thus, we can use the exture of the resulting deposits to give us clues to the mode of transport and deposition.

orting - The degree of uniformity of grain size. Particles become sorted on the basis of density, ecause of the energy of the transporting medium. High energy currents can carry larger agments. As the energy decreases, heavier particles are deposited and lighter fragments ontinue to be transported. This results in sorting due to density.

If the particles have the same density, then the heavier particles will also be larger, so the sorting will take place on the basis of size. We can classify this size sorting on a relative basis - well sorted to poorly sorted. Sorting gives clues to the energy conditions of the transporting medium from which the sediment was deposited.



Poorly Sorted Sediment

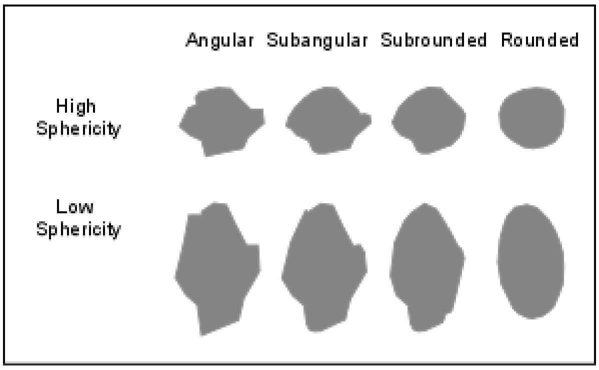


Well Sorted Sediment

Examples

- Beach deposits and wind blown deposits generally show good sorting because the energy of the transporting medium is usually constant.
- Stream deposits are usually poorly sorted because the energy (velocity) in a stream varies with position in the stream and time.

Rounding - During the transportation process, grains may be reduced in size due to abrasion. Random abrasion results in the eventual rounding off of the sharp corners and edges of grains. Thus, rounding of grains gives us clues to the amount of time a sediment has been in the transportation cycle. Rounding is classified on relative terms as well.



Sediment Maturity

Sediment Maturity refers to the length of time that the sediment has been in the sedimentary cycle. Texturally mature sediment is sediment that is well rounded, (as rounding increases with transport distance and time) and well sorted (as sorting gets better as larger clasts are left behind and smaller clasts are carried away. Because the weathering processes continues during sediment transport, mineral grains that are unstable near the surface become less common as the distance of transport or time in the cycle increases. Thus compositionally mature sediment is composed of only the most stable minerals.

For example a poorly sediment containing glassy angular volcanic fragments, olivine crystals and plagioclase is texturally immature because the fragments are angular, indicating they have not been transported very far and the sediment is poorly sorted, indicating that little time has been involved in separating larger fragments from smaller fragments. It is compositionally immature because it contains unstable glass along with minerals that are not very stable near the surface - olivine and plagioclase.On the other hand a well sorted beach sand consisting mainly of well rounded quartz grains is texturally mature because the grains are rounded, indicating a long time in the transportation cycle, and the sediment is well sorted, also indicative of the long time required to separate the coarser grained material and finer grained material from the sand. The beach sand is compositionally mature because it is made up only of quartz which is very stable at the earth's surface.

Types of Clastic Sedimentary Rocks

We next look at various clastic sedimentary rocks that result from lithification of sediment.

Conglomerates and Breccias

Conglomerate and Breccia are rocks that contain an abundance of coarse grained clasts (pebbles, cobbles, or boulders). In a conglomerate, the coarse grained clasts are well rounded, indicating that they spent considerable time in the transportation process and were ultimately deposited in a high energy environment capable of carrying the large clasts. In a breccia, the coarse grained clasts are very angular, indicating the the clasts spent little time in the transportation cycle.

Sandstones

A Sandstone is made of sand-sized particles and forms in many different depositional settings. Texture and composition permit historic interpretation of the transport and depositional cycle and sometimes allows determination of the source. Quartz is, by far, the dominant mineral in sandstones. Still there are other varieties. A Quartz arenite – is nearly 100% quartz grains. An Arkose contains abundant feldspar. In a lithic sandstone, the grains are mostly small rock fragments. A Wacke is a sandstone that contains more than 15% mud (silt and clay sized grains).. Sandstones are one of the most common types of sedimentary rocks.

Mudrocks

Mudrocks are made of fine grained clasts (silt and clay sized) . A siltstone is one variety that consists of silt-sized fragments. A shale is composed of clay sized particles and is a rock that tends to break into thin flat fragments A mudstone is similar to a shale, but does not break into thin flat fragments. Organic-rich shales are the source of petroleum.Fine grained clastics are deposited in non-agitated water, calm water, where there is little energy to continue to transport the small grains. Thus mudrocks form in deep water ocean basins and lakes.

Biochemical and Organic Sediments and Sedimentary Rocks

Biochemical and Organic sediments and sedimentary rocks are those derived from living organisms. When the organism dies, the remains can accumulate to become sediment or sedimentary rock. Among the types of rock produced by this process are:

Biochemical Limestone - calcite ($CaCO_3$) is precipitated by organisms usually to form a shell or other skeletal structure. Accumulation of these skeletal remains results in a limestone. Sometimes the fossilized remains of the organism are preserved in the rock, other times recrystallization during lithification has destroyed the remains. Limestones are very common sedimentary rocks.

Biochemical Chert - Tiny silica secreting planktonic organism like Radiolaria and Diatoms can accumulate on the sea floor and recrystallize during lithification to form biochemical chert. The recrystallization results in a hard rock that is usually seen as thin beds

Diatomite - When diatoms accumulate and do not undergo recrystallization, they form a white rock called diatomite as seen in the White Cliffs of Dover

Coal - Coal is an organic rock made from organic carbon that is the remains of fossil plant matter. It accumulates in lush tropical wetland settings and requires deposition in absence of Oxygen. It is high in carbon and can easily be burned to obtain energy.

Chemical Sediments and Sedimentary Rocks

Dissolved ions released into water by the weathering process are carried in streams or groundwater. Eventually these dissolved ions end in up in the ocean, explaining why sea water is salty. When water evaporates or the concentration of the ions get too high as a result of some other process, the ions recombine by chemical precipitation to form minerals that can accumulate to become chemical sediments and chemical sedimentary rocks. Among these are:

Evaporites - formed by evaporation of sea water or lake water. Produces halite (salt) and gypsum deposits by chemical precipitation as concentration of solids increases due to water loss by evaporation. This can occur in lakes that have no outlets (like the Great Salt Lake) or restricted ocean basins, like has happened in the Mediterranean Sea or the Gulf of Mexico in the past.

Travertine - Groundwater containing dissolve Calcium and bicarbonate ions can precipitate calcite to form a chemically precipitated limestone, called travertine. This can occur in lakes, hot springs, and caves.
Dolostones - Limestone that have been chemically modified by Mg-rich fluids flowing through the rock are converted to dolostones. $CaCO_3$ is recrystallized to a new mineral dolomite $CaMg(CO_3)_2$.

Chemical Cherts **-** Groundwater flowing through rock can precipitate SiO_2 to replace minerals that were present. This produces a non-biogenic chert. There are many varsities of such chert that are given different names depending on their attributes, For example:

Flint – Black or gray from organic matter.
Jasper – Red or yellow from Fe oxides.
Petrified wood – Wood grain preserved by silica.
Agate – Concentrically layered rings

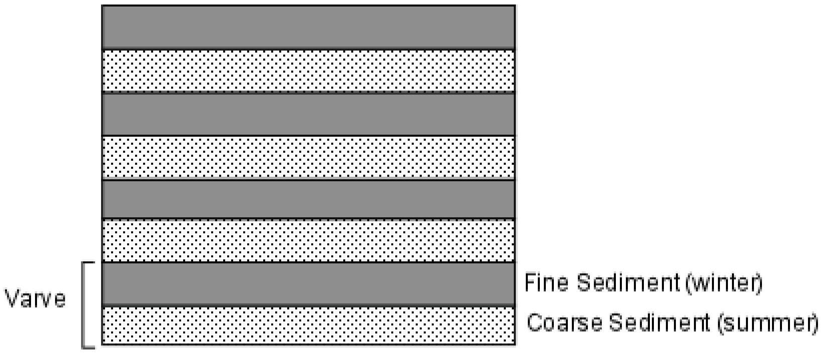
Sedimentary Structures

As mentioned previously, all stages of the sedimentary cycle leave clues to processes that were operating in the past. Perhaps the most easily observable clues are structures left by the depositional process. We here discuss sedimentary structures and the information that can be obtained from these structures.

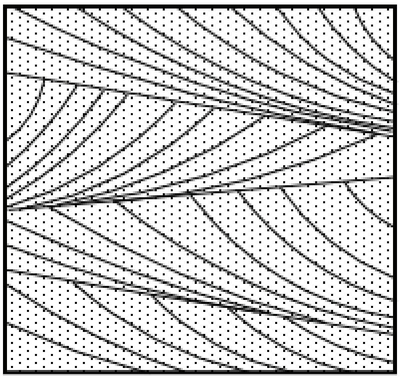
Stratification and Bedding

Because sediment is deposited in low lying areas that often extend over wide areas, successive depositional events produce layers called bedding or stratification that is usually the most evident feature of sedimentary rocks. The layering can be due to differences in color of the material, differences in grain size, or differences in mineral content or chemical composition. All of these differences can be related to differences in the environment present during the depositional events. A series of beds are referred to as strata. A sequence of strata that is sufficiently unique to be recognized on a regional scale is termed a formation. A formation is the fundamental geologic mapping unit.

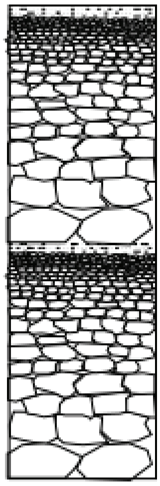
- ***Rhythmic Layering*** - Alternating parallel layers having different properties. Sometimes caused by seasonal changes in deposition (***Varves***). i.e. lake deposits wherein coarse sediment is deposited in summer months and fine sediment is deposited in the winter when the surface of the lake is frozen.



- ***Cross Bedding -*** Sets of beds that are inclined relative to one another. The beds are inclined in the direction that the wind or water was moving at the time of deposition. Boundaries between sets of cross beds usually represent an erosional surface. Very common in beach deposits, sand dunes, and river deposited sediment.

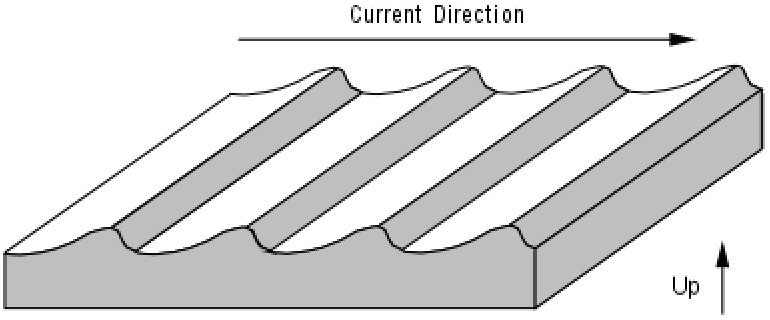


- ***Graded Bedding*** - As current velocity decreases, first the larger or more dense particles are deposited followed by smaller particles. This results in bedding showing a decrease in grain size from the bottom of the bed to the top of the bed. Sediment added as a pulse of turbid water. As pulse wanes, water loses velocity and sediments settle. Coarsest material settles first, medium next, then fine. Multiple graded-bed sequences called turbidites



- **Non-sorted Sediment -** Sediment showing a mixture of grain sizes results from such things as rockfalls, debris flows, mudflows, and deposition from melting ice.

- ***Ripple Marks*** - Water flowing over loose sediment creates bedforms by moving sediment with the flow.

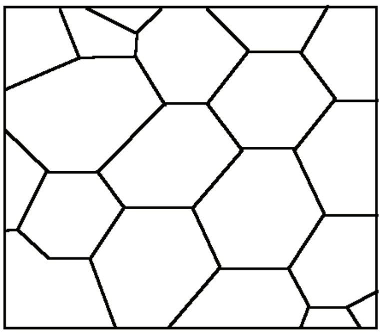


Bedforms are linked to flow velocity and sediment size. Ripples are characteristic of shallow water deposition and can also be caused by wind. blowing over the surface. Sand dunes are similar, but on a larger scale. Ripples are commonly preserved in sedimentary rocks.

Asymmetric ripples (as shown above) indicate flow direction,with the steep slope on the down - current direction. Ripples persevered in ancient rocks can also be indicators of up/down direction in the original sediment.

Symmetric ripples form as a result of constant wave energy oscillating back and forth.

- ***Mudcracks*** - result from the drying out of wet sediment at the surface of the Earth. The cracks form due to shrinkage of the sediment as it dries. When present in rock, they indicate that the surface was exposed at the earth's surface and then rapidly buried.



- ***Sole Marks*** **-** Flutes are troughs eroded in soft sediment that can become filled with mud. Both the flutes and the resulting casts (called flute casts) can be preserved in rock.

- ***Raindrop Marks*** - pits (or tiny craters) created by falling rain. If present, this suggests that the sediment was exposed to the surface of the Earth just prior to burial.

- ***Fossils -*** Remains of once living organisms. Probably the most important indicator of the environment of deposition.
    - Different species usually inhabit specific environments.
    - Because life has evolved - fossils give clues to relative age of the sediment.
    - Can also be important indicators of past climates.
- ***Rock Color***
    - Sulfides along with buried organic matter give rocks a dark color. Indicates deposition in a reducing environment.
    - Deposition in oxidizing environment produces red colored iron oxides and is often indicative of deposition in a non-marine environment. Such red colored rocks are often referred to as red beds.

Sedimentary Environments

If we look at various environments now present on Earth, we can find characteristics in the sediment that are unique to each environment. If we find those same characteristics in sedimentary rocks, it allows us to interpret the environment of the past. Each environment has its own energy regime and sediment delivery, transport and depositional conditions that are reflected in the sediment deposited.

Sedimentary Environments can be divided into the following

- Terrestrial (Non-marine) environments
    - Glacial
    - Alluvial fans
    - Sand Dunes
    - Mountain Streams
    - Lakes
    - Rivers
- Marine environments
    - Deltas
    - Coastal Beaches
    - Shallow Marine Clastics

- Shallow Marine Carbonates
- Deep Marine

We will cover most of these environments in more detail later in the course.
For now familiarize yourself with each of these by reading pages 220 to 227 in your text.

Transgressions and Regressions

Throughout geologic history sea level has risen and fallen by as much as a few hundred meters many times. These changes are the result of changes earth's climate or changes in the shape of the sea floor as a result of tectonics.

When sea level rises, the coast migrates inland. This is called a Transgression. Beach sand gets buried by marine sediments and the sea floor subsides due to the weight of the sediment. During a transgression, the beach sand forms an extensive layer, but does not all have the same age. When sea level falls, the coast migrates seaward. This is called a Regression. The sedimentary sequence then repeats itself in a vertical sense as the sedimentary environment migrates back and forth.

Diagenesis

LIthification of sediment into sedimentary rocks takes place after the sediment has been deposited and buried. The processes by which the sediment becomes lithified into a hard sedimentary rock is called diagenesis and includes all physical, chemical and biological processes that act on the sediment. The first step in diagenesis is the compaction of the sediment and loss of water as a result of the weight of the overlying sediment. Compaction and burial may cause recrystallization of the minerals to make the rock even harder. Fluids flowing through the rock and organisms may precipitate new minerals in the pore spaces between grains to form a cement that holds the sediment together. Common cements include quartz, calcite, and hematite.Other conditions present during diagenesis, such as the presence of absence of free oxygen may cause other alterations to the original sediment. In an environment where there is excess oxygen (Oxidizing Environment) organic remains will be converted to carbon dioxide and water. Iron will change from Fe^{2+} to Fe^{3+}, and will change the color of the sediment to a deep red (rust) color. In an environment where there is a depletion of oxygen (Reducing Environment), organic material may be transformed to solid carbon in the form of coal, or may be converted to hydrocarbons, the source of petroleum.Diagenesis is also a response to increasing the temperature and pressure as sediment gets buried deeper. As temperature increases beyond about 200^{o}C, we enter the realm of metamorphism, the subject of our next discussion.

Module-4

Geochemistry: It is the study of mechanisms behind major geological systems such as the Earth's crust and its oceans using various chemical tools.

It gives information regarding processes that control the abundance, composition and distribution of chemical compounds and isotopes in Earth.

Victor Goldschmidt (1888–1947) is often considered the 'father of geochemistry'. One of Goldschmidt's achievements was to begin to systematize the behaviour of the chemical elements in an Earth Sciences context via his classification of them according to their preferred host phases on silicate Earth (Lithophile*,* siderophile*,* chalcophile and atmophile*).*

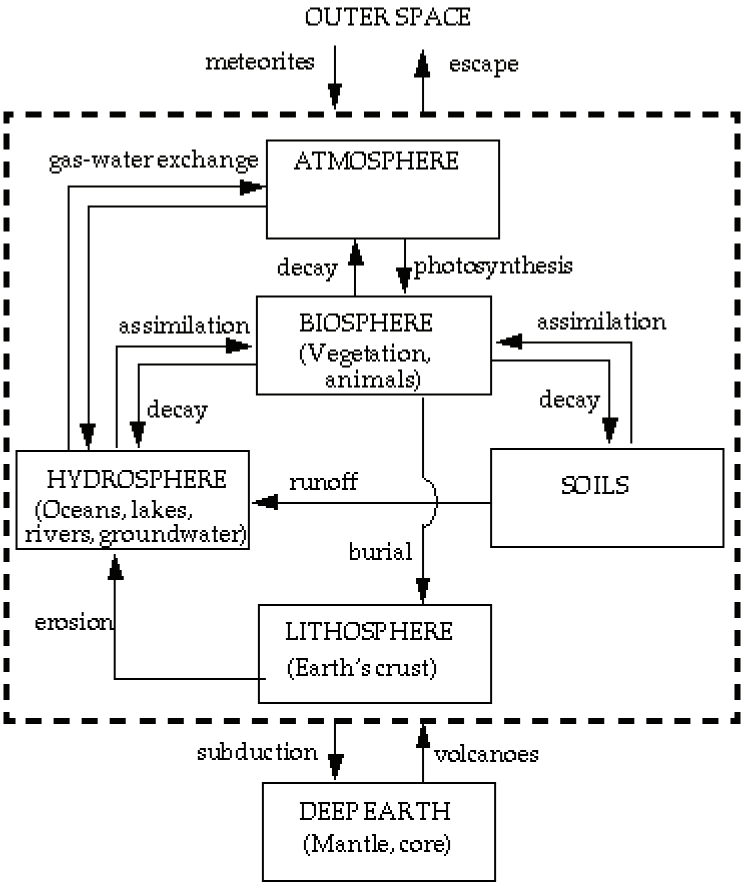
Geochemical Cycle:

So far we have viewed the concentrations of species in the atmosphere as controlled by emissions, transport, chemistry, and deposition. From an Earth system perspective, however, the composition of the atmosphere is ultimately controlled by the exchange of elements between the different reservoirs of the Earth. In the present chapter we examine atmospheric composition from this broader perspective, and focus more specifically on the biogeochemical factors that regulate the atmospheric abundances of N_2, O_2, and CO_2.

6.1 GEOCHEMICAL CYCLING OF ELEMENTS

The Earth system and its atmosphere is an assemblage of 92 natural elements. They are present in the Earth system since the formation of the Earth 4.5 billion years ago by gravitational accretion of a cloud of gases and dust. Subsequent inputs of material from extraterrestrial sources such as meteorites have been relatively unimportant. Escape of atoms to outer space is prevented by gravity except for the lightest atoms (H, He), and even for those it is extremely slow. Thus the assemblage of atoms composing the Earth system has been roughly conserved since the origin of the Earth. The atoms, in the form of various molecules, cycles continually between the different reservoirs of the Earth system. Geochemical cycling refers to the flow of elements within Earth's reservoirs; or flow in a closed system.

The cycling model is stated in the box below. The exchange of the element between two reservoirs is represented as a flow between the corresponding boxes.



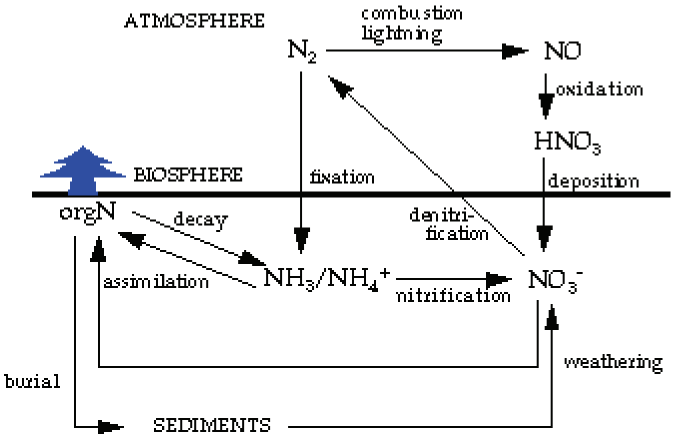
Geochemical cycle box model

Most of the mass of the Earth system is present in the deep Earth, but this material is largely isolated from the surface reservoirs: atmosphere, hydrosphere, biosphere, soil, and lithosphere. Communication between the deep Earth and the surface reservoirs takes place by volcanism and by subduction of tectonic plates, processes that are extremely slow compared to those cycling elements between the surface reservoirs. The abundance of an element in the atmosphere can therefore be viewed as determined by two separable factors: (a) the total abundance of the element in the ensemble of surface reservoirs, and (b) the partitioning of the element between the atmosphere and the other surface reservoirs.

The Nitrogen Cycle:

Nitrogen occupies about 78% of air on a molar basis. The figure below shows major processes involved in the cycling of nitrogen between surface reservoirs. Nitrogen is an essential component of the biosphere (think of the amino acids) and the atmosphere is an obvious source for this nitrogen. Conversion of the highly stable N_2 molecule to biologically available nitrogen, a process called fixation, is difficult. It is achieved in ecosystems by specialized symbiotic bacteria which can reduce atmospheric N_2 to ammonia (NH_3). The NH3 is assimilated as organic nitrogen by the bacteria or by their host plants, which may in turn be consumed by animals. Eventually these organisms excrete the nitrogen or die; the organic nitrogen is eaten by bacteria and mineralized to ammonium (NH_4+), which may then be assimilated by other organisms.

Bacteria may also use NH4+ as a source of energy by oxidizing it to nitrite (NO_2-) and on to nitrate (NO_3-). This process is called nitrification and requires the presence of oxygen (aerobic conditions). Nitrate is highly mobile in soil and is readily assimilated by plant and bacteria, providing another route for formation of organic nitrogen. Under conditions when O_2 is depleted in water or soil (anaerobic conditions), bacteria may use NO_3- as an alternate oxidant to convert organic carbon to CO_2. This process, called denitrification, converts NO_3- to N_2 and thus returns nitrogen from the biosphere to the atmosphere.

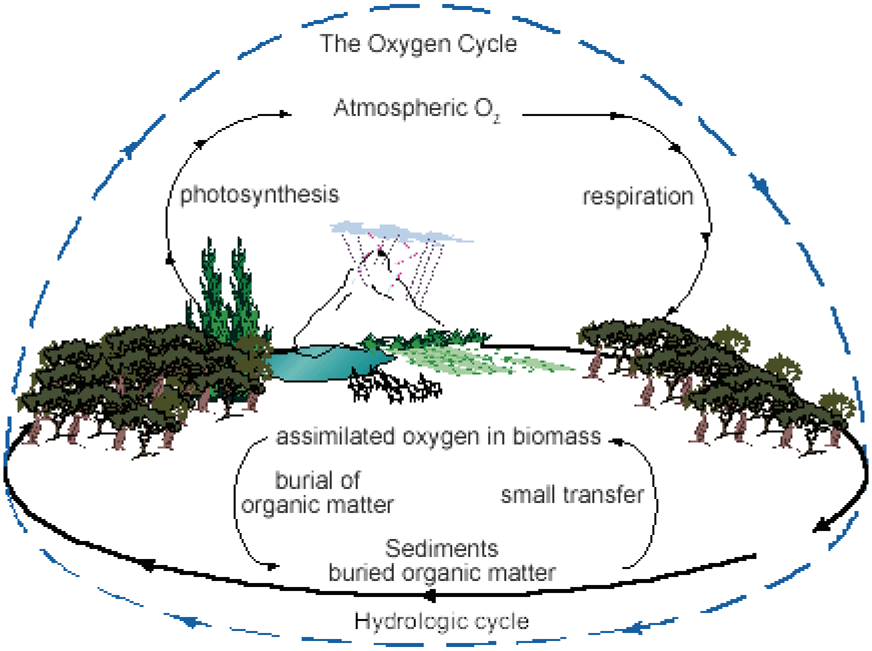


The nitrogen cycle: major processes

An additional pathway for fixing atmospheric N**2** is by high-temperature oxidation of N**2** to NO in the atmosphere during combustion or lightning, followed by atmospheric oxidation of NO to HNO**3** which is water-soluble and scavenged by rain. In industrial regions of the world, the fixation of N**2** in combustion engines provides a source of nitrogen to the biosphere that is much larger than natural N**2** fixation, resulting in an unintentional fertilization effect.

Transfer of nitrogen to the lithosphere takes place by burial of dead organisms (including their nitrogen) in the bottom of the ocean. These dead organisms are then incorporated into sedimentary rock. Eventually the sedimentary rock is brought up to the surface of the continents and eroded, liberating the nitrogen and allowing its return to the biosphere. This process closes the nitrogen cycle in the surface reservoirs.

Oxygen cycle:



The oxygen cycle is the cycle that helps move oxygen through the three main regions of the Earth, the Atmosphere, the Biosphere, and the Lithosphere. The Atmosphere is of course the region of gases that lies above the Earth's surface and it is one of the largest reservoirs of free oxygen on earth. The Biosphere is the sum of all the Earth's ecosystems. This also has some free oxygen produced from photosynthesis and other life processes. The largest reservoir of oxygen is the lithosphere. Most of this oxygen is not on its own or free moving but part of chemical compounds such as silicates and oxides.

The atmosphere is actually the smallest source of oxygen on Earth comprising only 0.35% of the Earth's total oxygen. The smallest comes from biospheres. The largest is as mentioned before in the Earth's crust. The Oxygen cycle is how oxygen is fixed for freed in each of these major regions.

In the atmosphere Oxygen is freed by the process called photolysis. This is when high energy sunlight breaks apart oxygen bearing molecules to produce free oxygen. One of the most well known photolysis it the ozone cycle. O2 oxygen molecule is broken down to atomic oxygen by the ultra violet radiation of sunlight. This free oxygen then recombines with existing O_2 molecules to make O_3 or ozone. This cycle is important because it helps to shield the Earth from the majority of harmful ultra violet radiation turning it to harmless heat before it reaches the Earth's surface. In the biosphere the main cycles are respiration and photosynthesis. Respiration is when animals and humans breathe consuming oxygen to be used in metabolic process and exhaling carbon dioxide. Photosynthesis is the reverse of this process and is mainly done by plants and plankton.

The lithosphere mostly fixes oxygen in minerals such as silicates and oxides. Most of the time the process is automatic all it takes is a pure form of an element coming in contact with oxygen such as what happens when iron rusts. A portion of oxygen is freed by chemical weathering. When a oxygen bearing mineral is exposed to the elements a chemical reaction occurs that wears it down and in the process produces free oxygen.These are the main oxygen cycles and each play an important role in helping to protect and maintain life on the Earth.

Carbon Cycle:

Carbon is the life-support on Earth. Most of the living things are made up of carbon, and our civilizations our economies, our homes, our means of transport are built on carbon. We need carbon, but that need is also entwined with one of the most serious problems facing us today: global climate change. Forged in the heart of aging stars, carbon is the fourth most abundant element in the Universe. Most of Earth's carbon about 65,500 billion metric tons is stored in rocks. The rest is in the ocean, atmosphere, plants, soil, and fossil fuels.

Carbon flows between each reservoir in an exchange called the carbon cycle, which has slow and fast components. Any change in the cycle that shifts carbon out of one reservoir puts more carbon in the other reservoirs. Changes that put carbon gases into the atmosphere result in warmer temperatures on Earth. Over the long term, the carbon cycle seems to maintain a balance that prevents all of Earth's carbon from entering the atmosphere (as is the case on Venus) or from being stored entirely in rocks. This balance helps keep Earth's temperature relatively stable, like a thermostat.

This thermostat works over a few hundred thousand years, as part of the slow carbon cycle. This means that for shorter time periods tens to a hundred thousand years the temperature of Earth can vary. And, in fact, Earth swings between ice ages and warmer interglacial periods on these time scales. Parts of the carbon cycle may even amplify these short-term temperature changes.

Geochemical classification of elements:

Elements can be qualitatively classified into major (>0.4 wt %), minor (0.1–0.4 wt%), and trace elements (<0.1 wt %). Major elements are those that define the primary structure of a given phase, which can be a mineral, liquid, or vapor. The most acceptable geochemical classification is Gold Smith's classification. Elements are often categorized based on their general geochemical behaviors even though an element's chemical behavior depends strongly on variables such as temperature, pressure, and chemical environment; the latter of which can dictate an element's valence state and ability to form complexes. These classifications broadly follow Goldschmidt's original classifications (Goldschmidt, 1937) with the addition of organophile and fluid-mobile elements.

Lithophile Elements:

Lithophile elements are those that remain on or close to the surface because they combine readily with oxygen, forming compounds that do not sink into the core. The lithophile elements include:Al, B, Ba, Be, Br, Ca, Cl, Cr, Cs, F, I, Hf, K, Li, Mg, Na, Nb, O, P, Rb, Sc, Si, Sr, Ta, Th , Ti, U, V, Y, Zr, W and the lanthanides.

Lithophile elements mainly consist of the highly reactive metals of the s- and f-blocks. They also include a small number of reactive nonmetals, and the more reactive metals of the d-block such as titanium, zirconium and vanadium. Lithophile derives from "lithos" which means "rock", and "phile" which means "love".

Most lithophile elements form very stable ions with an electron configuration of a noble gas (sometimes with additional f-electrons). The few that do not, such as silicon, phosphorus and boron, form extremely strong covalent bonds with oxygen – often involving pi bonding. Their strong affinity for oxygen causes lithophile elements to associate very strongly with silica, forming relatively low-density minerals that thus float to the crust. The more soluble minerals formed by the alkali metals tend to concentrate in seawater or extremely arid regions where they can crystallise. The less soluble lithophile elements are concentrated on ancient continental shields where all soluble minerals have been weathered.

Because of their strong affinity for oxygen, most lithophile elements are enriched in the Earth's crust relative to their abundance in the solar system. The most reactive s- and f-block metals, which form either saline or metallic hydrides, are known to be extraordinarily enriched on Earth as a whole relative to their solar abundances. This is because during the earliest stages of the Earth's formation the reaction that controlled the stable form of each chemical element was its ability to form compounds with hydrogen. Under these conditions, the s- and f-block metals were strongly enriched during the formation of the Earth. The most enriched elements are rubidium, strontium and barium, which between them account for over 50 percent by mass of all elements heavier than iron in the Earth's crust.

The nonmetallic lithophiles – phosphorus and the halogens – exist on Earth as ionic salts with s-block metals in pegmatites and seawater. With the exception of fluorine, whose hydride forms hydrogen bonds and is therefore of relatively low volatility, these elements have had their concentrations on Earth significantly reduced through escape of volatile hydrides during the Earth's formation. Although they are present in the Earth's crust in concentrations quite close to their solar abundances, phosphorus and the heavier halogens are probably significantly depleted on Earth as a whole relative to their solar abundances.

Several transition metals, including chromium, molybdenum, iron and manganese, show *both* lithophile *and* siderophile characteristics and can be found in both these two layers. Although these metals form strong bonds with oxygen and are never found in the Earth's crust in the free state, metallic forms of these elements are thought very likely to exist in the core of the earth as relics from when the atmosphere did not contain oxygen. Like the "pure" siderophiles, these elements (except iron) are considerably depleted in the crust relative to their solar abundances.

Owing to their strong affinity for oxygen, lithophile metals, although they form the great bulk of the metallic elements in Earth's crust, were never available as free metals before the development of electrolysis. With this development, many lithophile metals are of considerable value as structural metals (magnesium, aluminium, titanium, vanadium) or as reducing agents (sodium, magnesium, calcium). The process of smelting these metals is extremely energy-intensive. With emissions of greenhouse gases suspected of contributing to climate change, the use of these elements as industrial metals is called into question, despite the depletion of rarer and less reactive chalcophile metals leaving few substitutes.

The non-metals phosphorus and the halogens were also not known to early chemists, though production of these elements is less difficult than of metallic lithophiles since electrolysis is required only with fluorine. Elemental chlorine is particularly important as an oxidizing agent – usually being made by electrolysis of sodium chloride.

Siderophile elements:

Siderophile (from sideron, "iron", and philia, "love") elements are the transition metals which tend to sink into the core because they dissolve readily in iron either as solid solutions or in the molten state, although some sources include elements which are not transition metals in their list of siderophiles, such as germanium. Other sources may also differ in their list based on the temperature being discussed - niobium, vanadium, chromium, and manganese may be considered siderophiles or not, depending on the assumed temperature and pressure. Also confusing the issue is that some elements, such as the aforementioned manganese, as well as molybdenum, form strong bonds with oxygen, but in the free state (as they existed on the primitive Earth when free oxygen did not exist) can mix so easily with iron that they do not concentrate in the siliceous crust, as do true lithophile elements. Iron, meanwhile, is simply everywhere.The siderophile elements include the highly siderophilic ruthenium, rhodium, palladium, rhenium, osmium, iridium, platinum, and gold, the moderately siderophilic cobalt and nickel, in addition to the "disputed" elements mentioned earlier - some sources even include tungsten and silver. Most siderophile elements have practically no affinity whatsoever for oxygen: indeed oxides of gold are thermodynamically unstable with respect to the elements. They form stronger bonds with carbon or sulfur, but even these are not strong enough to separate out with the chalcophile elements. Thus, siderophile elements are bound through metallic bonds with iron in the dense layer of the Earth's core, where pressures may be high enough to keep the iron solid. Manganese, iron, and molybdenum do form strong bonds with oxygen, but in the free state (as they existed on the primitive Earth when free oxygen did not exist) can mix so easily with iron that they do not concentrate in the siliceous crust, as do true lithophile elements. However, ores of manganese are found in much the same sites as are those of aluminium and titanium, owing to manganese's great reactivity towards oxygen.

Because they are so concentrated in the dense core, siderophile elements are known for their rarity in the Earth's crust. Most of them have always been known as precious metals because of this. Iridium is the rarest transition metal occurring within the Earth's crust, with an abundance by mass of less than one part per billion. Mineable deposits of precious metals usually form as a result of the erosion of ultramafic rocks, but are not highly concentrated even compared to their crustal abundances, which are typically several orders of magnitude below their solar abundances. However, because they are concentrated in the mantle and core, siderophile elements are believed to be present in the Earth as a whole (including the core) in something approaching their solar abundances.

Chalcophile Elements:

These elements include: Ag, As, Bi, Cd, Cu, Ga, Ge, Hg, In, Pb, S, Sb, Se, Sn, Te, Tl and Zn.

Chalcophile elements are those that remain on or close to the surface because they combine readily with sulfur and some other chalcogen other than oxygen, forming compounds which do not sink into the core.Chalcophile elements are those metals and heavier nonmetals that have a low affinity for oxygen and prefer to bond with sulfur as highly insoluble sulfides. Chalcophile derives from Greek khalkós , meaning "ore" (it also meant "bronze" or "copper", but in this case "ore" is the relevant meaning), and is taken to mean "chalcogen-loving" by various sources.

Because these sulfides are much denser than the silicate minerals formed by lithophile elements, chalcophile elements separated below the lithophiles at the time of the first crystallization of the Earth's crust. This has led to their depletion in the Earth's crust relative to their solar abundances, though because the minerals they form are nonmetallic, this depletion has not reached the levels found with siderophile elements.However, because they formed volatile hydrides on the primitive Earth when the controlling redox reaction was the oxidation or reduction of hydrogen, the less metallic chalcophile elements are strongly depleted on Earth as a whole relative to cosmic abundances. This is most especially true of the chalcogens selenium and tellurium (which formed volatile hydrogen selenide and hydrogen telluride, respectively), which for this reason are among the rarest elements found in the Earth's crust (to illustrate, tellurium is only about as abundant as platinum).The most metallic chalcophile elements (of the copper, zinc and boron groups) may mix to some degree with iron in the Earth's core. They are not likely to be depleted on Earth as a whole relative to their solar abundances since they do not form volatile hydrides. Zinc and gallium are somewhat "lithophile" in nature because they often occur in silicate or related minerals and form quite strong bonds with oxygen. Gallium, notably, is sourced mainly from bauxite, an aluminum hydroxide ore in which gallium ion substitutes for chemically similar aluminum.

Although no chalcophile element is of high abundance in the Earth's crust, chalcophile elements constitute the bulk of commercially important metals. This is because, whereas lithophile elements require energy-intensive electrolysis for extraction, chalcophiles can be easily extracted by reduction with coke, and chalcophiles' geochemical concentration – which in extreme cases can exceed 100,000 times average crustal abundance. These greatest enrichments occur in high plateaux like the Tibetan Plateau and the Bolivian altiplano where large quantities of chalcophile elements have been uplifted through plate collisions. A side-effect of this in modern times is that the rarest chalcophiles (like mercury) are so completely exploited that their value as minerals has almost completely disappeared.

Atmophile Elements:

The atmophile elements are: H, C, N and the noble gases.

Atmophile elements (also called "volatile elements") are defined as those that remain mostly on or above the surface because they are, or occur in, liquids and/or gases at temperatures and pressures found on the surface. The noble gases do not form stable compounds and occur as monatomic gases, while nitrogen, although it does not have a stable configuration for its individual atoms, forms a diatomic molecule so strong that all oxides of nitrogen are thermodynamically unstable with respect to nitrogen and oxygen. Consequently, with the development of free oxygen through photosynthesis, ammonia was oxidised to molecular nitrogen which has come to form four-fifths of the Earth's atmosphere. Carbon is also classed as an atmophile because it forms very strong multiple bonds with oxygen in carbon monoxide (slowly oxidised in the atmosphere) and carbon dioxide. The latter is the fourth-largest constituent of the Earth's atmosphere, while carbon monoxide occurs naturally in volcanoes and has a residence time in the atmosphere of a few months.

Hydrogen, which occurs in the compound water, is also classed as an atmophile. Water is classified as a volatile, because most of it is liquid or gas, even though it does exist as a solid compound on the surface.Because all atmophile elements are either gases or form volatile hydrides, atmophile elements are strongly depleted on earth as a whole relative to their solar abundances owing to losses from the atmosphere during the formation of the Earth. The heavier noble gases (krypton, xenon) are the rarest stable elements on Earth.

Types of Meteorites:

It is often said that when the average person imagines what a meteorite looks like, they think of an iron. It is easy to see why. Iron meteorites are dense, very heavy, and have often been forged into unusual or even spectacular shapes as they plummet, melting, through our planet's atmosphere. Though irons may be synonymous with most people's perception of a typical space rock's appearance, they are only one of three main meteorite types, and rather uncommon compared to stone meteorites, especially the most abundant stone meteorite group-the ordinary chondrites.Although there are a large number of sub classes, meteorites are divided into three main groups: irons, stones and stony-irons. Almost all meteorites contain extraterrestrial nickel and iron, and those that contain no iron at all are so rare that when we are asked for help and advice on identifying possible space rocks, we usually discount anything that does not contain significant amounts of metal. Much of meteorite classification is based, in fact, on how much iron a specimen does contain.

Iron Meteorites

When I give lectures and slideshows about meteorites to rock and mineral societies, museums, and schools, I always enjoy commencing the presentation by passing around a softball-sized iron meteorite. Most people have never held a space rock in their hands and when someone does pick up an iron meteorite for the first time their face lights up and their reaction is, almost without fail, to exclaim: "Wow, it's so heavy!"

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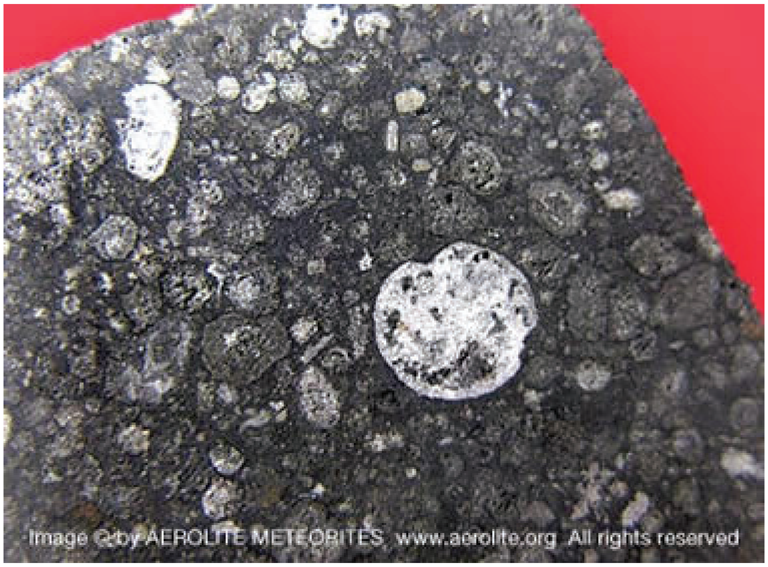
Iron meteorites were once part of the core of a long-vanished planet or large asteroid and are believed to have originated within the Asteroid Belt between Mars and Jupiter. They are among the densest materials on earth and will stick very strongly to a powerful magnet. Iron meteorites are far heavier than most earth rocks-if you've ever lifted up a cannon ball or a slab of iron or steel, you'll get the idea.In most specimens of this group, the iron content is approximately 90 to 95% with the remainder comprised of nickel and trace elements. Iron meteorites are subdivided into classes both by chemical composition and structure. Structural classes are determined by studying their two component iron-nickel alloys: kamacite and taenite.

These alloys grow into a complex interlocking crystalline pattern known as the Widmanstätten Pattern, after Count Alois von Beckh Widmanstätten who described the phenomenon in the 19th Century. This remarkable lattice-like arrangement can be very beautiful and is normally only visible when iron meteorites are cut into slabs, polished, and then etched with a mild solution of nitric acid. The kamacite crystals revealed by this process are measured and the average bandwidth is used to subdivide iron meteorites into a number of structural classes. An iron with very narrow bands, less than 1mm, would be a "fine octahedrite" and those with wide bands would be called "coarse octahedrites."

Stone Meteorites

The largest group of meteorites is the stones, and they once formed part of the outer crust of a planet or asteroid. Many stone meteorites-particularly those that have been on the surface of our planet for an extended period of time-frequently look much like terrestrial rocks, and it can take a skilled eye to spot them when meteorite hunting in the field. Freshly fallen stones will exhibit a black fusion crust, created as the surface literally burned during flight, and the vast majority of stones contain enough iron for them to easily adhere to a powerful magnet.

Some stone meteorites contain small, colorful, grain-like inclusions known as "chondrules." These tiny grains originated in the solar nebula, and therefore pre-date the formation of our planet and the rest of the solar system, making them the oldest known matter available to us for study. Stone meteorites that contain these chondrules are known as "chondrites."



Space rocks without chondrites are known as "achondrites." These are volcanic rocks from space which formed from igneous activity within their parent bodies where melting and recrystallization eradicated all trace of ancient chondrules. Achondrites contain little or no extraterrestrial iron, making them much more difficult to find than most other meteorites, though specimens often display a remarkable glossy fusion crust which looks almost like enamel paint.

Stony-Iron Meteorites

The least abundant of the three main types, the stony-irons, account for less than 2% of all known meteorites. They are comprised of roughly equal amounts of nickel-iron and stone and are divided into two groups: pallasites and mesosiderites. The stony-irons are thought to have formed at the core/mantle boundary of their parent bodies.Pallasites are perhaps the most alluring of all meteorites, and certainly of great interest to private collectors. Pallasites consist of a nickel-iron matrix packed with olivine crystals. When olivine crystals are of sufficient purity, and display an emerald-green color, they are known as the gemstone peridot. Pallasites take their name from a German zoologist and explorer, Peter Pallas, who described the Russian meteorite Krasnojarsk, found near the Siberian capital of the same name in the 18th Century. When cut and polished into thin slabs, the crystals in pallasites become translucent giving them a remarkable otherworldly beauty.

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The mesosiderites are the smaller of the two stony-iron groups. They contain both nickel-iron and silicates and usually show an attractive, high-contrast silver and black matrix when cut and polished-the seemingly random mixture of inclusions leading to some very striking features. The word mesosiderite is derived from the Greek for "half" and "iron," and they are very rare. Of the thousands of officially cataloged meteorites, fewer than one hundred are mesosiderites.

Module-5

Sampling and sampling methods

According to Park and Barter Sampling is the process of taking a small part of an article,such that the consistenceyod that portion shall be representative of the same.

Sampling methods include both surtificial and Underground sampling methods.the classification is as follows:

1. SURFICIAL SAMPLING METHOD:

i) Channel Sampling

ii) Groove sampling

iii) Muck sampling

iv) Dump sampling

v) Grab sampling

2. UNDERGROUND SAMPLING METHOD:

i) Face sampling

  a) Regular channel or groove sampling

  b) Pick sampling

ii) Grab sampling

  a) Muck pile sampling

  b) car and chute sampling

iii) Bulk sampling

iv) Drill sampling

  a) Churn drill sampling

  b) Diamond drill sampling

  c) Rock drill sampling (with piston and hammer)

Underground Sampling

A rock sample for geothermal exploration is typically collected from a drilled well, and initial analysis of the rock type, mineralization, composition, textures, etc. are collected in the field at the drill site or from core and cutting samples that have since been stored in a repository. However, the more in depth rock properties often require laboratory tools.

Surface Sampling

There are rock samples that can be collected on the surface, in outcrop, which may reveal important information about the geothermal resource at depth. These hand samples can be collected using a rock hammer or sledge.

Grab Sampling:

A specimen picked up from ore or mineral deposit or a portion of mineralized rock is a grab sample.

It is not true sampling but the samples collected gives preliminary idea about nature and grade of the whole deposit. All the material collected are undergone coning and quartering method.

Channel or groove or trench sampling:

Most acceptable method, useful for bedded, banded and vein type of deposit. It consists of cutting the channel across the face of exposed ore and collecting resulting chips, fragments and dust from each channel. In some cases the channel may also be cut along a line making a small angle with thickness of the deposit

Chip or point sampling:

It is a less laborious method and useful because it is a regular method of known samples, is used for hard or uniform ores where it is difficult to cut channels. The samples are collected by taking a small series of chips of rocks in a regular grid pattern from the working face in a regular interval. The blasted and broken materials are sampled. Shape of grid is adapted to the morphology and structure of deposit. Since it is highly productive, it is advantageous to use.

Face or muck or Lump sampling:

The term face/group of point sampling covers sampling of exposed face of ore and waste. One of three lumps of rocks are gathered in the face are taken from a pile of broken mineral with the purpose of finding deforming mineral and also the chemical composition. It is very simple, quick and cheap procedure but the accuracy of this method is very low.

Bulk Sampling:

It refers to the order of few tones of samples collected either from trench, pits or channels or from run of mine.

e.g.in case of barite which occur as box work, the mineral is collected by sorting out the various grades of barites to obtain barite on Kg. per cubic meter for each grade. ThIs enables the estimation of reserve.

Drill hole sampling:

Most core **samples** are obtained by **drilling** with special drills into the substance, such as sediment or rock, with a hollow steel tube, called a core **drill**. The **hole** made for the core **sample** is called the "core **hole**". A variety of core samplers exist to **sample** different media under different conditions.it helps in identifying deposit boundary.this method is classified based on type of equipment employed.

Planar sampling:

Very rare method of sampling.

Used for low mineral content deposits like gold.

Error in sampling:

Due to various factors numerous errors are possible in case of samplingas well as in analysis. There are mainly two types of error-

Random error and systematic error

The error in sampling is mainly due to-

- Improper spacing in samples
- Insufficient number of samples
- Improper location of samples
- Improper chemical analysis


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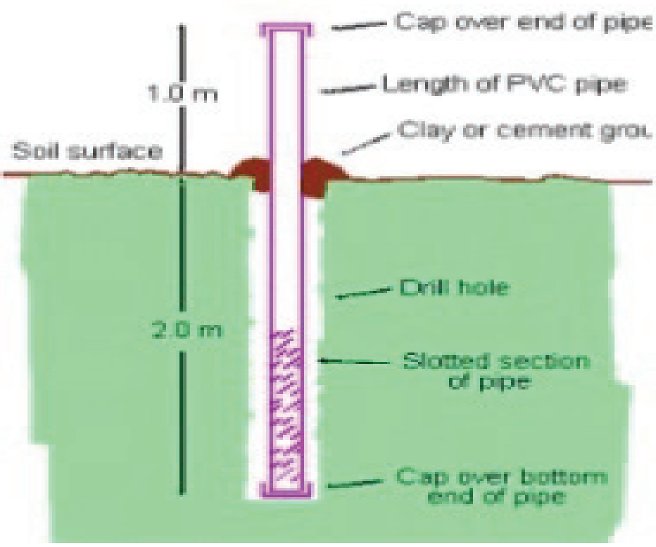
Cap over end of pipe
1.0 m
Length of PVC pipe
Clay or cement grou
Soil surface
Drill hole
2.0 m
Slotted section of pipe
Cap over bottom end of pipe