# Introduction to the science of geology

Earth Science is the study of the Earth and its neighbors in space. It is an exciting science with many interesting and practical applications. Some Earth scientists use their knowledge of the Earth to locate and develop energy and mineral resources. Others study the impact of human activity on Earth's environment and design methods to protect the planet. Some use their knowledge about Earth processes such as volcanoes, earthquakes and hurricanes to plan communities that will not expose people to these dangerous events.

*The Four Earth Sciences*:

Many different sciences are used to learn about the earth, however, the four basic areas of Earth science study are: geology, meteorology, oceanography and astronomy.

*Geology: Science of the Earth:*
Geology is the primary Earth science. The word means "study of the Earth". Geology deals with the composition of Earth materials, Earth structures, and Earth processes. It is also concerned with the organisms of the planet and how the planet has changed over time. Geologists search for fuels and minerals, study natural hazards, and work to protect Earth's environment.

Geology gives insight into the history of the Earth by providing the primary evidence for plate tectonics, the evolutionary history of life, and past climates. Geology is important for mineral and hydrocarbon exploration and exploitation, evaluating water resources, understanding of natural hazards, the remediation of environmental problems, and for providing insights into past climate change. Geology also plays a role in geotechnical engineering and is a major academic discipline.

Geologists use a number of field, laboratory, and numerical modeling methods to decipher Earth history and to understand the processes that occur on and inside the Earth. In typical geological investigations, geologists use primary information related to petrology (the study of rocks), stratigraphy (the study of sedimentary layers), and structural geology (the study of positions of rock units and their deformation). In many cases, geologists also study modern soils, rivers, landscapes, and glaciers; investigate past and current life and biogeochemical pathways, and use geophysical methods to investigate the subsurface.

*Meteorology: Science of the Atmosphere*

*Oceanography: Science of the Oceans*

 *Astronomy is the study of the universe.*

**The Importance of Geology:**

 Today we live in a time when the Earth and its inhabitants face many challenges. Our climate is changing and that change is being caused by human activity. Earth scientists recognized this problem and will play a key role in efforts to resolve it. We are also challenged to: develop new

sources of energy that will have minimal impact on climate; locate new sources of metals and other mineral resources as known sources are depleted; and, determine how Earth's increasing population can live and avoid serious threats such as volcanic activity, earthquakes, landslides, floods and more. These are just a few of the problems where solutions depend upon a deep understanding of Geology.

# Crust of earth and its composition

All bodies in the solar system are believed to have been formed by the condensation and accretion of the primitive interstellar material that made up the solar nebula. The composition of the Sun is the same as the average composition of this material. Gravitational energy was released during accretion, and together with the radioactive decay of short-lived radioactive nuclides eventually led to heating of the proto-Earth so that it differentiated into a radially symmetric body made up of a series of shells whose density increased towards its center. The differentiation prevents any estimate being made of the overall composition of the Earth by direct sampling. However, it is believed that meteorites are representatives of material within the solar nebula and that estimates of the Earth's composition can be made from them. The presence of metallic and silicate phases in meteorites is taken to indicate that the Earth consists of an iron/nickel core surrounded by a lower density silicate mantle and crust. Seismic data, combined with knowledge of the mass and moment of inertia of the Earth, have revealed that the mean atomic weight of the Earth is about 27, with a contribution of 22.4 from the mantle and crust and 47.0 from the core. No single type of meteorite possesses an atomic weight of 27, the various types of chondrite being somewhat lower and iron meteorites considerably higher. However, it is possible to mix the proportions of different meteorite compositions in such a way as to give both the correct atomic weight and core/mantle ratio.

1: 32.4% iron meteorite (with 5.3% FeS) and 67.6% oxide portion of bronzite chondrites.

2: 40% type I carbonaceous chondrite, 50% ordinary chondrite, and 10% iron meteorite (containing 15% sulfur).

3: Nonvolatile portion of type I carbonaceous chondrites with FeO/FeO + MgO of 0.12 and suffi cient SiO2 reduced to Si to yield a metal/silicate ratio of 32/68.

4: Based on Ca, Al, Ti = 5 × type I carbonaceous chondrites, FeO = 12% to accommodate lunar density, and Si/Mg = chondritic ratio

|    | Earth | | | Moo |
|----|------|------|------|------|
|    | 1 | 2 | 3 | 4 |
| Fe | 34.6 | 29.3 | 29.9 | 9.3 |
| O  | 29.5 | 30.7 | 30.9 | 42.0 |
| Si | 15.2 | 14.7 | 17.4 | 19.6 |
| Mg | 12.7 | 15.8 | 15.9 | 18.7 |
| Ca | 1.1 | 1.5 | 1.9 | 4.3 |
| Al | 1.1 | 1.3 | 1.4 | 4.2 |
| Ni | 2.4 | 1.7 | 1.7 | 0.6 |
| Na | 0.6 | 0.3 | 0.9 | 0.07 |
| S  | 1.9 | 4.7 | – | 0.3 |

**Table:** *Estimates of the bulk composition of the Earth and Moon (in weight percent) (from Condie,1982a).*

It is apparent that at least 90% of the Earth is made up of iron, silicon, magnesium, and oxygen, with the bulk of the remainder comprising calcium, aluminum, nickel, sodium, and possibly sulfur.

The crust is compositionally distinct outermost rocky layer of the Earth. The crust is a thin but important zone where dry, hot rock from the deep Earth reacts with the water and oxygen of the surface, making new kinds of minerals and rocks. It's also where plate-tectonic activity mixes and scrambles these new rocks and injects them with chemically active fluids. Finally, the crust is the home of life, which exerts strong effects on rock chemistry and has its own systems of mineral recycling. All of the interesting and valuable variety in geology, from metal ores to thick beds of clay and stone, finds its home in the crust and nowhere else. Common rocks in the crust. *Igneous rocks*: granite, gabbro, basalt. *Metamorphic rocks*: gneiss, schist and amphibolite. *Sedimentary rocks*: sandstone, shale, limestone.

| Element | Mass percent | Common minerals | Common rocks |
|---|---|---|---|
| Oxygen | 46.6 | Silicates, oxides, etc. Oxygen is extremely widespread in the crust and very reactive as well. Volumetrically insignificant part of all the minerals contain no oxygen. | Almost every common rock type contains oxygen. Only sulfide ore bodies and evaporite beds are almost free of oxygen, but they are volumetrically relatively insignificant. |
| Silicon | 27.7 | Silicon has its very own large group of minerals known as silicates. More than 90% of the crust is composed of silicate minerals. Silicon and oxygen are the two most common chemical elements in the crust that also happen to like each other's company very much. Pure silicon oxide is known as mineral quartz which makes up 12% of the crust. There is not a single common non-silicate mineral that contains silicon — silicon always combines with oxygen. | Silicate minerals are the building blocks of most common rock types (basalt, granite, schist, gneiss, sandstone, etc.). Carbonate rocks (limestone, dolomite rock) and evaporates (gypsum rock, rock salt) are notable exceptions. They do not contain silicon if they are pure. Opaque ore minerals (oxides and sulfides) are frequent minor components of most rock types. They are also free of silicon. |
| Aluminum | 8.1 | Very widespread in silicate minerals (feldspar, clay minerals, mica). Aluminum hydroxides (boehmite, diaspore, | Feldspars are very common minerals in the crust, more than half (51%) of the crust is made up of this mineral group. Mica and clay |

| Element | Mass percent | Common minerals | Common rocks |
|---|---|---|---|
| | | gibbsite) are economically important as aluminum ore minerals. | minerals are also common, both comprise about 5% of the crust. Hence, aluminum is extremely widespread as well. It is usually not very concentrated in silicate minerals, though. Aluminum has been extracted from silicate rocks very rarely. Bauxite which is aluminum-rich laterite formed in humid hot areas contains aluminum hydroxides and is primarily mined for aluminum. Aluminum in bauxite is a residue of chemical weathering of silicate rocks. |
| Iron | 5.0 | Iron is a widespread element in minerals. Notable iron-rich silicate minerals are pyroxenes, amphiboles, olivine, black micabiotite, garnet, etc. Iron is also an important element in sedimentary rocks. It is just like aluminum hard to dissolve and carry away with water. Iron is common in lateritic soil and forms rust-colored iron oxide mineral hematite. Hematite is responsible for the red coloration of many minerals and rock types. Iron oxide magnetite is common as an accessory mineral in metamorphic and igneous rocks. Iron sulfide pyrite is the most common sulfide mineral. Iron also occurs in carbonates (siderite, ankerite), clay minerals (glauconite, chlorite). Iron is a strong chromophore element, it gives dark coloration to its host minerals. This is why most pyroxenes and amphiboles are | Iron is actually the single most abundant chemical element in the whole of Earth, but most of it is in the core. Basalt, gabbro, amphibolite, greenschist, etc. are the most notable crustal rocks that contain lots of iron. There is a large number of rock types that contain significant amount of iron, but most of the iron mined comes from metamorphosed sedimentary rocks known as BIF (banded iron formation). |

| Element | Mass percent | Common minerals | Common rocks |
|---|---|---|---|
| | | black. | |
| Calcium | 3.6 | Calcium is also very widespread. It is always present in plagioclase feldspars (39% of the crust), but the amount of calcium varies there. The most important pyroxenes and amphiboles (augite and hornblende) contain calcium. Calcium occurs in many other silicate minerals like garnet, epidote, wollastonite, titanite, etc. Calcium is a constituent of calcite which is very important mineral chiefly in sedimentary environments. Calcium phosphate apatite is a common mineral as well. Gypsum is a major evaporite mineral that is chemically hydrated calcium sulfate. Calcium fluoride is known as mineral fluorite. | Occurs equally successfully in igneous, sedimentary, and metamorphic rocks. Especially well-known calcium-bearing rock type is limestone. Its metamorphosed equivalent is marble. Marble is composed of calcite just like limestone. Calcite is a remarkable mineral. Even igneous rock composed of pure calcite exists. It is known as carbonatite, but it is very rare when compared with limestone and marble. Calcium tends to be part of minerals like plagioclase, pyroxenes and amphiboles in igneous rocks. Major calcium-bearing metamorphic rock is amphibolite (metamorphosed basalt, calcium is hosted by hornblende and plagioclase). Phosphorite is another important calcium-bearing sedimentary rock (calcium is hosted by phosphate mineral apatite). Calcium also occurs in evaporites as a mineral gypsum. |
| Sodium | 2.8 | Sodium is widespread in silicate minerals. It is an important constituent of both alkali feldspar and plagioclase. Sodium-bearing pyroxenes are relatively rare. Sodium is somewhat more widespread in amphiboles but not as much as calcium. Well-known sodium-bearing silicate mineral is tourmaline. Sodium is an important component of feldspathoids, but both feldspathoids and tourmaline | Igneous and metamorphic rocks that contain feldspar. Much of sodium from weathered igneous and metamorphic rocks is dissolved in seawater. Rock salt is the most important sodium-bearing sedimentary rock. |

| Element | Mass percent | Common minerals | Common rocks |
|---|---|---|---|
| | | group minerals are relatively rare. Major sodium-bearing mineral in sedimentary environments is halite (NaCl). | |
| Potassium | 2.6 | Potassium and sodium are similar chemical elements both chemically and geologically. Potassium is an important constituent of alkali feldspars. Most alkali feldspars contain much more potassium than sodium and are therefore frequently referred to as K-feldspars. Important potassium-bearing silicate minerals are micas (5% of the crust). Biotite and muscovite are the most important micas and they both contain potassium. Most important potassium-bearing sedimentary mineral is sylvite (KCl). | Alkali feldspars and micas are common rocks in silicate igneous and metamorphic rocks (granite, gneiss, schist, etc.). Much of potassium from weathered igneous and metamorphic rocks is dissolved in seawater. Sylvite is not as common evaporite as halite (rock salt) because it takes much higher evaporation rate to precipitate sylvite. |
| Magnesium | 2.1 | Magnesium is very widespread in the mantle beneath the crust. Olivine and pyroxene are the most important Mg-bearing minerals there and these minerals are also constituents of some crustal rocks, especially dark-colored igneous rocks. Amphiboles also contain magnesium but less than pyroxenes. Magnesium ion is similar to iron in size and can therefore easily replace iron in the lattice of minerals. This is the case in olivine, pyroxenes, amphiboles and even micas (phlogopite is a Mg-rich variety of biotite). Important Mg-rich minerals in metamorphic rocks | Important Mg-bearing igneous rocks are ultramafic rocks (peridotite, pyroxenite). Rocks that contain lots of pyroxenes like basalt and gabbro contain Mg also but to a lesser extent. Metamorphic Mg-rich rocks are serpentinite and talc schist. Most important Mg-bearing sedimentary rock is dolomite rock which is former limestone converted to dolomite by Mg-rich meteoric water percolating limestone. |

| Element | Mass percent | Common minerals | Common rocks |
|---------|--------------|-----------------|--------------|
| | | are talc and serpentine. Magnesium in the sedimentary environment occurs chiefly in carbonates dolomite and magnesite. Lots of magnesium is dissolved in seawater. Magnesium is extracted from seawater. | |
| Others | 1.5 | Other common elements in the crust are titanium, hydrogen, phosphorous, manganese, fluorine, etc. Their occurrence is somewhat more restricted, but they are all important elements in minerals and rocks. Hydrogen is actually extremely widespread constituent of a wide array of minerals, but it is the lightest chemical element and therefore does not form a significant part of the crust by mass. | |
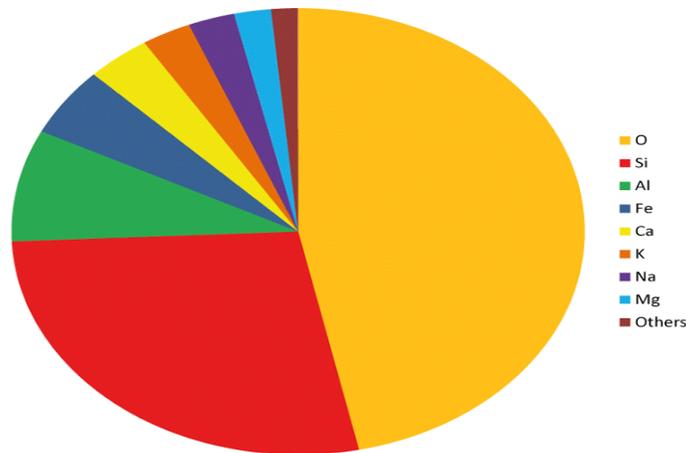


*Chemical elements in the crust:*

The most common chemical elements in the crust are oxygen (46.6%), silicon (27.7), aluminum (8.1), iron (5.0), calcium (3.6), potassium (2.8), sodium (2.6), and magnesium (2.1). This is an estimation of the chemical composition of the crust based on our understanding of the relative proportions of different rock types in the crust and their average composition. Our understanding is limited for sure because the average continental crust is more than 40 km thick but we have no way to sample it directly. Deepest mines reach only 4 kilometers and deepest drillhole is 12 km deep.
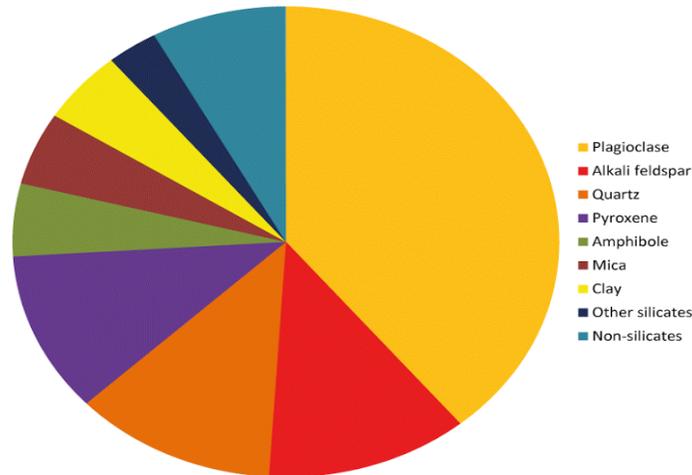
*The most abundant minerals in the crust:* More than 90% on the crust is composed of silicate minerals. Most abundant silicates are feldspars (plagioclase (39%) and alkali feldspar (12%)). Other common silicate minerals are quartz (12%) pyroxenes (11%), amphiboles (5%), micas (5%), and clay minerals (5%). The rest of the silicate family comprises 3% of the crust. Only 8% of the crust is composed of non-silicates — carbonates, oxides, sulfides, etc.

*The most abundant rock types in the crust:*

Rocks are divided into three broad groups: igneous, metamorphic, and sedimentary rocks. The oceanic crust is largely composed of basaltic igneous rocks which are covered by a thin veneer of sediments which are thickest near the margins of the continental landmasses. The continental crust is much thicker and older. The continental crust is also much more variable and structurally very complex. Virtually all the rock types known to man occur in the continental crust. Even meteorites, xenoliths from the mantle, and ophiolites (fragment of former oceanic crust) are constituents of the continental crust because that's where we found them.

Roughly three fourths of the continental crust is covered by sedimentary rocks and almost all of it is covered by loose sediments (soil, sand, dirt, etc.). We are most likely to encounter these materials, but it is important to understand that despite being so ubiquitous on the surface, they make up only about 8% of the whole mass of the crust. Sediments consolidate to sedimentary rocks after burial. Sand turns to sandstone, limy mud to limestone, clay to claystone. Sedimentary rocks are stable only in the upper parts of the crust. High pressure and temperature in the deeper parts metamorphoses them (minerals recrystallize) to various metamorphic rocks. The bulk of the continental crust is made of metamorphic rocks. Igneous rocks are also common on the surface in volcanically active regions, but they also occur deeper in the crust as granitic (mostly) intrusions.

Important sediments are sand, clay, mud (wet mixture of clay and fine sand), and limy mud. Widespread sedimentary rocks are limestone (2% of the crust by volume), sandstone (1.7%),

claystone (4.2%) which are lithified versions of the loose sediments mentioned before. Chemical sediments like halite and gypsum are important as well, but their overall volume is clearly less than 1% of the crust. Important igneous rocks are granite, granodiorite, gabbro, basalt, diorite, andesite, etc. It is very difficult to say what the percentage of these rocks is. Important metamorphic rocks are metamorphosed equivalents of widespread sedimentary and igneous rocks. Common metamorphic rocks are slate (metamorphosed claystone), schist (met. claystone, higher grade than slate) quartzite (met. sandstone), marble (met. limestone), gneiss (met. igneous rock or sedimentary rocks), and amphibolite (met. basaltic rocks).

# Minerals and Rocks.

- "A mineral is an element or chemical compound that is normally crystalline and that has been formed as a result of geological processes" (Nickel, E. H., 1995).

- "Minerals are naturally-occurring inorganic substances with a definite and predictable chemical composition and physical properties." (O' Donoghue, 1990).

- "A mineral is a naturally occurring homogeneous solid, inorganically formed, with a definite chemical composition and an ordered atomic arrangement" (Mason, et al,1968).

- "These... minerals ...can be distinguished from one another by individual characteristics that arise directly from the kinds of atoms they contain and the arrangements these atoms make inside them" (Sinkankas, 1966).

- "A mineral is a body produced by the processes of inorganic nature, having usually a definite chemical composition and, if formed under favorable conditions, a certain characteristic atomic structure which is expressed in its crystalline form and other physical properties" (Dana & Ford, 1932).

- "Every distinct chemical compound occurring in inorganic nature, having a definite molecular structure or system of crystallization and well-defined physical properties, constitutes a mineral species" (Brush & Penfield, 1898).

A relatively hard, naturally occurring mineral material. Rock can consist of a single mineral or of several minerals that are either tightly compacted or held together by a cement like mineral matrix. The three main types of rock are igneous, sedimentary, and metamorphic.

*Igneous rocks* are formed from the solidification of molten rock material. There are two basic types.
*Intrusive igneous rocks* crystallize below Earth's surface, and the slow cooling that occurs there allows large crystals to form. Examples of intrusive igneous rocks are diorite, gabbro, granite, pegmatite, and peridotite.
*Extrusive igneous rocks* erupt onto the surface, where they cool quickly to form small crystals. Some cool so quickly that they form an amorphous glass. These rocks include andesite, basalt, obsidian, pumice, rhyolite, scoria, and tuff.
Igneous rocks are classified according to their silica content. Rocks that contain lots of silica are usually light-colored. Most important minerals are feldspars and quartz. These rocks are referred to as felsic rocks (feldspar + silica). Common felsic rocks are granite and rhyolite. Mafic rocks are low in silica but relatively high in magnesium and iron. They are dark-colored and named mafic rocks (magnesium + ferric). However, no matter whether they are felsic or mafic, these rocks always contain much more silicon than magnesium or iron. Important minerals in mafic rocks are pyroxene, plagioclase and sometimes also olivine or amphibole. There are also rocks intermediate in composition (diorite and andesite).

*Sedimentary rocks* are formed by the accumulation of sediments. There are three basic types of sedimentary rocks.

*Clastic sedimentary* rocks such as breccia, conglomerate, sandstone, siltstone, and shale are formed from mechanical weathering debris.

*Chemical sedimentary* rocks, such as rock salt, iron ore, chert, flint, some dolomites, and some limestones, form when dissolved materials precipitate from solution.

*Organic sedimentary* rocks such as coal, some dolomites, and some limestones, form from the accumulation of plant or animal debris.

**Metamorphic rocks** have been modified by heat, pressure, and chemical processes, usually while buried deep below Earth's surface. Exposure to these extreme conditions has altered the mineralogy, texture, and chemical composition of the rocks.

There are two basic types of metamorphic rocks. *Foliated metamorphic* rocks such as gneiss, phyllite, schist, and slate have a layered or banded appearance that is produced by exposure to heat and directed pressure.

*Non-foliated* metamorphic rocks such as hornfels, marble, quartzite, and novaculite do not have a layered or banded appearance.

# Weathering of Rocks; Erosion, transportation and deposition by wind, Water and ice.

The decomposition and disintegration of rock is a primary process in the tectonic cycle and landscape evolution. Weathering is the breakdown of rocks by mechanical disintegration and chemical decomposition. Many rocks form under high temperatures and pressures deep in the Earth's crust. When exposed to the lower temperatures and pressures at the Earth's surface and brought into contact with air, water, and organisms, they start to decay. The process tends to be self-reinforcing: weathering weakens the rocks and makes them more permeable, so rendering them more vulnerable to removal by agents of erosion, and the removal of weathered products exposes more rock to weathering. Living things have an influential role in weathering, attacking rocks and minerals through various biophysical and biochemical processes, most of which are not well understood.
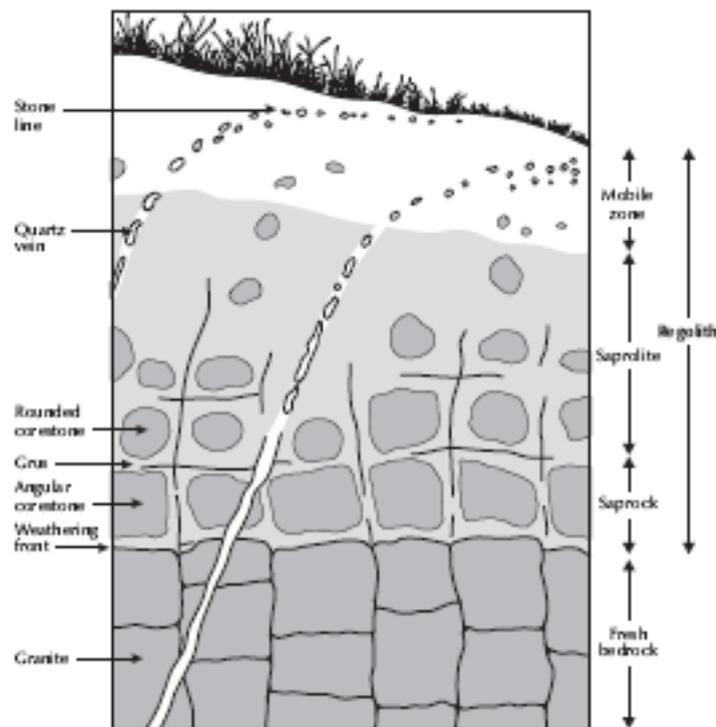
Fig: Typical weathering profile in granite. The weathering front separates fresh bedrock from the regolith.The regolith is divided into saprock, saprolite, and a mobile zone.

### Weathering and Climate

Weathering processes and weathering crusts differ from place to place. These spatial differences are determined by a set of interacting factors, chiefly rock type, climate, topography, organisms, and the age of the weathered surface. Climate is a leading factor in determining chemical, mechanical, and biological weathering rates. Temperature influences the rate of weathering, but seldom the type of weathering. As a rough guide, a 10◦C rise in temperature speeds chemical reactions, especially sluggish ones, and some biological reactions by a factor of two to three, a

fact discovered by Jacobus Hendricusvan't Hoff in 1884. The storage and movement of water in the regolith is a highly influential factor in determining weathering rates, partly integrating the influence of all other factors. Louis Peltier (1950) argued that rates of chemical and mechanical weathering are guided by temperature and rainfall conditions (Figure 6.3). The intensity of chemical weathering depends on the availability of moisture and high air temperatures. It is minimal in dry regions, because water is scarce, and in cold regions, where temperatures are low and water is scarce (because it is frozen for much or all of the year). Mechanical weathering depends upon the presence of water but is very effective where repeated freezing and thawing occurs. It is therefore minimal where temperatures are high enough to rule out freezing and where it is so cold that water seldom thaws.
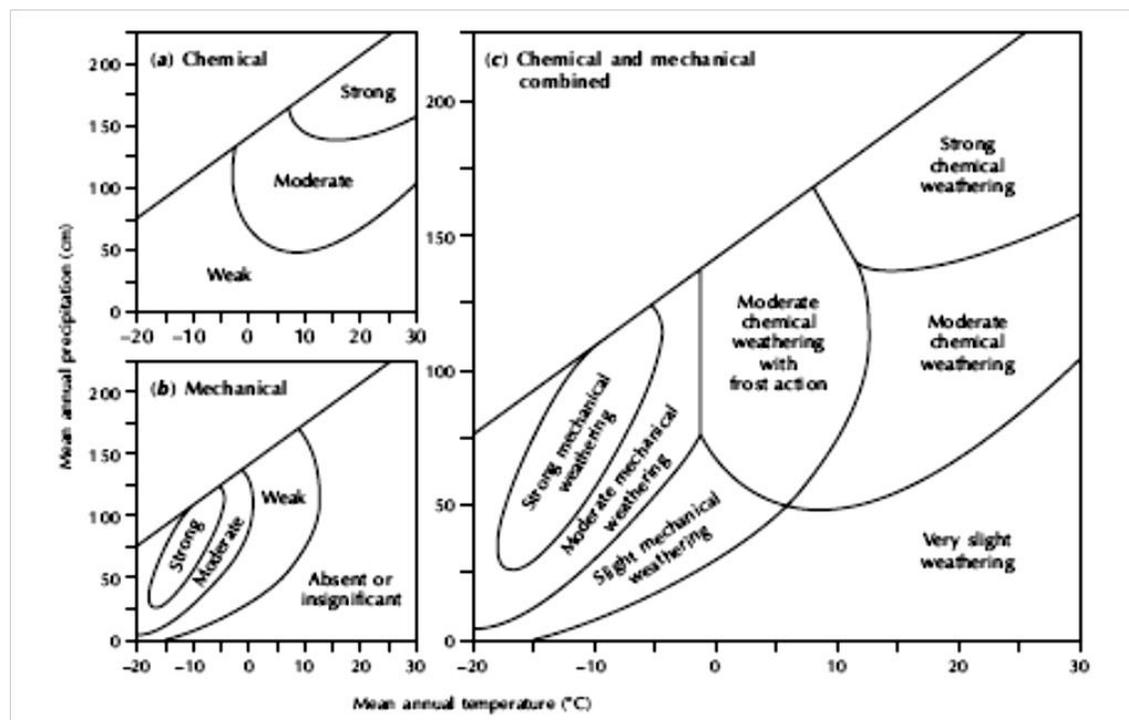


*Figure:* Louis Peltier's scheme relating chemical and mechanical weathering rates to temperature and rainfall.
*Source:* Adapted from Peltier (1950)

**Weathering patterns:**
Given that the neoformation of clay minerals is strongly influenced by the leaching regime of the regolith, it is not surprising that different climatic zones nurture distinct types of weathering and weathering crust. Several researchers have attempted to identify **zonal patterns in weathering** (e.g. Chernyakhovsky *et al.* 1976; Duchaufour 1982).One scheme, which extendsGeorges Pedro's work, recognizes sixweathering zones (Figure) (Thomas 1994):
1 The *allitization zone* coincides with the intense leaching regimes of the humid tropics and is associated with the tropical rainforest of the Amazon basin, Congo basin, and South-East Asia.
2 The *kaolinization zone* accords with the seasonal leaching regime of the seasonal tropics and is associated with savannah vegetation.

3 The *smectization zone* corresponds to the subtropical and extratropical areas, where leaching is relatively weak, allowing smectite to form. It is found in many arid and semi-arid areas and in many temperate areas.

4 The *little-chemical-weathering zone* is confined to hyperarid areas in the hearts of large hot and cold deserts.

5 The *podsolization zone* conforms to the boreal climatic zone.

6 The *ice-cover zone*, where, owing to the presence of ice sheets, weathering is more or less suspended.

Within each of the first five zones, parochial variations arise owing to the effect of topography, parent rock, and other local factors. Podsolization, for example, occurs under humid tropical climates on sandy parent materials.
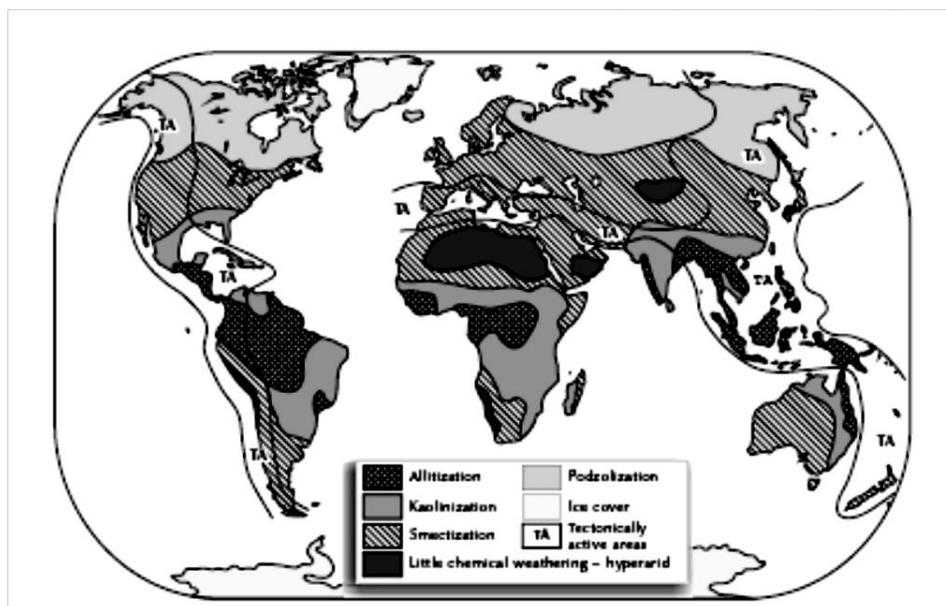


*Figure 6.4* The main weathering zones of the Earth. *Source:* Adapted from Thomas (1974, 5)

**Erosion** is a natural process which is usually made by rock and soil being loosened from the erosion earth's surface at one location and moved to another. Erosion changes the landscape by wearing down mountains, filling in valleys, and making rivers appear and disappear. It is usually a slow and gradual process that occurs over thousands or millions of years. But erosion can be speeded up by such human activities as farming and mining. Erosion begins with a process called weathering; in this process, environmental factors break rock and soil into smaller pieces, and loosen them from the earth's surface.

When the wind whips up a dust storm that stings our eyes, its ability to move sand is very clear. But the most powerful erosive force on the earth is not wind but water, which causes erosion in its solid form of ice and as a liquid. Water in its liquid form causes erosion in many ways. Streams from tiny creeks to huge rivers carry tons of eroded soil and rocks every year. The size of eroded materials a stream can carry depends on the speed of the stream, and the turbulence or

roughness of the water; a fast turbulent stream can carry large rocks, while a slow gently flowing stream carries only particles of sand and clay.

Not all rock or soil react the same to the forces of erosion; hard rock that contains many cracks may wear away faster than softer rock because the cracks can cause big chunks of the rock to break. Soft rock will lose just tiny bits at a time. Most soils erode more quickly than rocks, since soil is made of smaller particles that are more easily washed or worn away.

*Types of Erosion by Water:*

*Splash Erosion*: Small soil particles are detached and sent airborne through the impact of raindrops on soil.

*Sheet Erosion*: Raindrops break apart the soil structure and it's moved downslope by water that flows overland as a sheet rather than definitive channels. This occurs frequently during cloud bursts.

*Rill Erosion*: This process develops small, short-lived, concentrated flow paths. These paths creates a sediment source and delivery system for hillslope erosion. Areas where precipitation rates exceed soil infiltration rates are more prone to this type of erosion.

*Gully Erosion*: Water flows in narrow channels during or directly following heavy rains or melting snow. The gullies can erode to considerable depths.

*Valley or Stream Erosion*: Continual water flow alongside land (along a linear feature) creates this type of erosion. It extends downward, deepening a valley, and headward, extending the valley into the hillside. This occurs most frequently in times of flooding.

*Bank Erosion*: Over time, banks of rivers and streams are naturally worn down.

Water Erosion Control:

The greatest way to restore eroded land is very simple: Vegetation. Plants grow and colonize creating deep root systems protecting the soil from water in its various forms. As simple as the solution is, a little help never hurts. Coir is natural coconut fiber that will protect the soil while the plants grow. Woven geotextiles and non-woven geotextiles separate soils, filter water, and reinforce the ground.

*Glaciers*

Glaciers erode predominantly by three different processes: abrasion/scouring, plucking, and ice thrusting. In an abrasion process, debris in the basal ice scrapes along the bed, polishing and gouging the underlying rocks, similar to sandpaper on wood. Glaciers can also cause pieces of bedrock to crack off in the process of plucking. In ice thrusting, the glacier freezes to its bed, then as it surges forward, it moves large sheets of frozen sediment at the base along with the glacier. This method produced some of the many thousands of lake basins that dot the edge of the Canadian Shield. The erosion caused by glaciers worldwide erodes mountains so effectively that the term glacial buzz-saw has become widely used, which describes the limiting effect of glaciers on the height of mountain ranges. As mountains grow higher, they generally allow for more glacial activity (especially in the accumulation zone above the glacial equilibrium line altitude), which causes increased rates of erosion of the mountain, decreasing mass faster than isostatic rebound can add to the mountain. This provides a good example of a negative feedback loop. Ongoing research is showing that while glaciers tend to decrease mountain size, in some areas, glaciers can actually reduce the rate of erosion, acting as a glacial armor. These processes,

combined with erosion and transport by the water network beneath the glacier, leave moraines, drumlins, ground moraine (till), kames, kame deltas, moulins, and glacial erratics in their wake, typically at the terminus or during glacier retreat.

### *Wind erosion*

Wind erosion is a major geomorphological force, especially in arid and semi-arid regions. It is also a major source of land degradation, evaporation, desertification, harmful airborne dust, and crop damage—especially after being increased far above natural rates by human activities such as deforestation, urbanization, and agriculture.



Wind erosion is of two primary varieties: *deflation*, where the wind picks up and carries away loose particles; and *abrasion*, where surfaces are worn down as they are struck by airborne particles carried by wind. Deflation is divided into three categories: (1) *surface creep*, where larger, heavier particles slide or roll along the ground; (2) *saltation*, where particles are lifted a short height into the air, and bounce and saltate across the surface of the soil; and (3) *suspension*, where very small and light particles are lifted into the air by the wind, and are often carried for long distances. Saltation is responsible for the majority (50-70%) of wind erosion, followed by suspension (30-40%), and then surface creep (5-25%).

Wind erosion is much more severe in arid areas and during times of drought. For example, in the Great Plains, it is estimated that soil loss due to wind erosion can be as much as 6100 times greater in drought years than in wet years.

# Introduction to geological structures

**Geologic structures** are usually the result of the powerful tectonic forces that occur within the earth. These forces fold and break rocks, form deep faults, and build mountains.

Mountains are the most conspicuous landforms in Idaho. Any isolated mass of rock may be called a mountain because no minimum height or shape is required. Mountains may be formed by volcanoes, by erosional processes and by structural processes such as faulting and folding. The topographic elevation of mountains reflects a balance between uplift and forces of erosion.

*Volcanic Mountains*

There are many volcanic mountains in southern Idaho, particularly within the Snake River Plain Province. These mountains generally consist of individual cones of cinder and extrusive igneous rock. The volcanic material was extruded through a central vent in the earth's crust and piled up on the surface to form a cone. In Idaho, volcanic mountains tend to be smaller than other types of mountains, generally less than 1,000 feet high. They also tend to be isolated and erratically distributed, although they are commonly aligned along rifts or fissures such as the Great Rift of the Snake River Plain. Volcanic mountains are generally dome to conical shaped and are symmetrical in plan view. As a general rule, volcanic mountains consisting mostly of cinders and tuffaceous material are the most susceptible to erosion of all mountains.

*Erosional Mountains*

Erosional mountains are found in regions of crustal uplift such as the central Idaho uplands. They are characterized by steep gorges, precipitous slopes and youthful streams. Idaho's erosional mountains have primarily been carved by glaciers and running water and are the result of hundreds of thousands of years of erosion in the intervening valleys.

*Structural Mountains*

Structural mountains were created by structural activity such as folding and faulting. The Basin and Range Province of eastern Idaho is an outstanding example of mountains created by faulting. In the Basin and Range Province, large elongate blocks of the earth's crust were moved up relative to the intermontane valleys along large normal faults.

A **fault** is a fracture or zone of fractures between two blocks of rock. **Faults** allow the blocks to move relative to each other. This movement may occur rapidly, in the form of an earthquake - or may occur slowly, in the form of creep. There are three different types of faults: *Normal, Reverse, and Transcurrent (Strike-Slip)*. *Normal faults* form when the hanging wall drops down. The forces that create normal faults are pulling the sides apart, or extensional. *Reverse faults* form when the hanging wall moves up. Large faults within the Earth's crust result from the action of plate tectonic forces, with the largest forming the boundaries between the plates, such as subduction zones or transform faults. Energy release associated with rapid movement on active faults is the cause of most earthquakes.
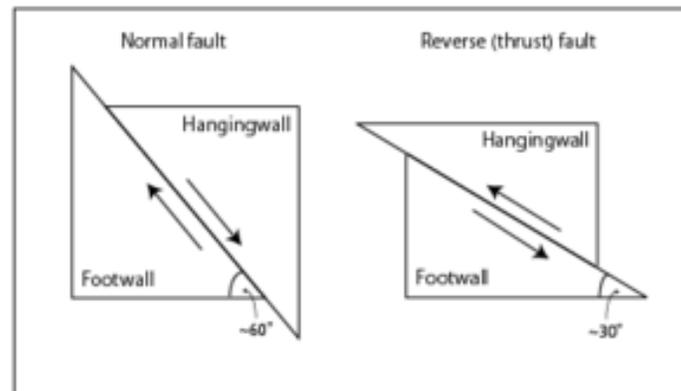
*Dip-slip faults*

Dip-slip faults can occur either as "reverse" or as "normal" faults. A normal fault occurs when the crust is extended. Alternatively such a fault can be called an extensional fault. The hanging wall moves downward, relative to the footwall. A downthrown block between two normal faults dipping towards each other is called a graben. An upthrown block between two normal faults

dipping away from each other is called a horst. Low-angle normal faults with regional tectonic significance may be designated detachment faults.

A reverse fault is the opposite of a normal fault—the hanging wall moves up relative to the footwall. Reverse faults indicate compressive shortening of the crust. The dip of a reverse fault is relatively steep, greater than 45°.

A thrust fault has the same sense of motion as a reverse fault, but with the dip of the fault plane at less than 45°. Thrust faults typically form ramps, flats and fault-bend (hanging wall and foot wall) folds.



Cross-sectional illustration of normal and reverse dip-slip faults

***Folds:***
We often think of rock as hard, brittle material. Throw a rock hard enough on the ground and it will likely break into pieces. But under the right conditions, rock can actually 'flow' in a way that keeps it from breaking. When rock deforms in such a way that it bends instead of breaking, we call this a fold. Folds come from pressure on rocks that occur over very long periods of time (think millions of years), so instead of a quick action like throwing the rock on the ground, it's more like standing on it for millions of years until the pressure is finally enough that it changes shape.

*Types of Folds*
Folds are created in rock when they experience compressional stress. This is when the rock is being pushed inward from both sides. This is like if you put a spring between your hands and push them together. As you push, you're compressing the spring, and rock can be compressed in the same way over long periods of time. There are different types of folds created by compressional stress depending on which way the rock bends.

*An anticline* is a fold that arches up as both sides of the rock are pushed inward. You can remember that the anticline creates this type of fold because the arch looks like an 'A' (for anticline).

*A syncline* is a fold that sinks down as both sides of the rock are pushed inward. You can remember that a syncline creates this type of fold because the fold 'sinks' downward, which sounds like 'syncline.'

*A monocline* is a fold where the rock layers form an S-shape as the sides of the rock are compressed. You can remember this type of fold because all the layers of rock are still horizontal, going in one direction instead of bending vertically upward or downward like

anticlines and synclines. And since 'mono' means 'one,' monoclines are layers in only 'one direction.'

We also have *domes*, which are like anticlines but instead of an arch, the fold is in a dome shape, like an inverted bowl. Similarly, there are also *basins*, which are like synclines but again, instead of a sinking arch, the fold is in a shape of a bowl sinking down into the ground.

### *Joints*

A brittle-fracture surface in rocks along which little or no displacement has occurred. Present in nearly all surface rocks, joints extend in various directions, generally more toward the vertical than to the horizontal. Joints may have smooth, clean surfaces, or they may be scarred by slickensides, or striations. Jointing does not extend to a very great depth in the Earth's crust, because at about 12 kilometres (7.5 miles) even rigid rocks tend to flow plastically in response to stress.

In unweathered rocks, joints are relatively inconspicuous, but upon weathering they become marked, especially in a soluble rock such as limestone. Solution by water percolating through joints has led to the formation of large caves and underground rivers. Quarrying operations are facilitated by the presence of a well-developed joint system.

Sedimentary rocks usually show two sets of joints at right angles to one another, each extending down perpendicular to the bedding; one set extends in the direction of dip and the other in the direction of strike (trend of the line of intersection of the bedding and the horizontal). The distance between joints varies from about two centimetres to a few hundred metres; in alternating strata the degree of jointing may vary from bed to bed and in some cases is related to the compaction of sediments during rock formation.

In igneous rocks, jointing is generally quite irregular; but in granite, two vertical sets forming right angles to one another on the top surface and another set of cross joints approximately horizontal occur frequently. (These cross joints are the effect of weathering.) Intrusions of molten rock, when cooled, form sills and dikes, which, in many places, show columnar jointing. Three sets of joints perpendicular to the cooling surfaces intersect each other at angles of about 120°. These form polygonal columns of rock that range from about 7–8 centimetres (3 inches) to about 6 metres (19 feet) in diameter; the size depends on the rate of cooling of the intrusive rock—the faster the cooling, the smaller the columns.

The principal cause of jointing in both stratified and igneous rocks is crustal movement, although the specific origin of the movement may not always be apparent. Contraction upon consolidation of sediment, as well as crystallization, also contributes to minor irregular jointing, as does expansion and contraction from the intrusion of hot igneous rocks.

# Rock forming minerals and ore forming minerals. Processes of mineral formation. Physical properties of minerals.

The study of geology means understanding the crust of the Earth. That crust consists of rocks and
Minerals. Rocks are a mixture of minerals. A single rock may not have the same mixture of minerals all the way through, and the size of the mineral crystals may change too. Characteristics that define minerals include:

1) The elements in a mineral are bound together in a repeating pattern that determines the specific shape of a mineral crystal.
2) Minerals have a distinct inorganic chemical composition. Most minerals are compounds of several elements.
3) Minerals are nonliving, although minerals may be concentrated by living organisms, such as calcium in our bones and mineral enrichment zones around deep oceanic volcanic vents that support bacterial colonies rich in zinc and other heavy metals.
4) Minerals occur in a solid state at room temperature.
5) Minerals occur naturally on Earth.
6) Minerals have distinct physical properties.

The identification of minerals is like being a detective. Through a series of basic tests, the properties of the mineral are determined, and possibilities are eliminated one by one until the mineral is identified. The properties of minerals commonly tested for with a mineral test kit are:

*Color*—some minerals have a characteristic identifying color.
Luster—a description of the way a mineral's surface looks in reflected light. Is it pearly, metallic, or dull?
*Shape*—the specific shape of a mineral crystal is characteristic of its component elements.
*Hardness*—most mineral test kits use the Mohs Hardness Scale. The Mohs scales runs from 1 (talc) to 10 (diamond).
*Specific gravity*—this is the comparison of a mineral's weight to the same volume of water. Specific gravity does not change.
*Streak*—this is the color a mineral makes when scratched on a rough white porous ceramic surface.
*Cleavage*—the shape a mineral takes when it is broken.
*Unusual properties*—include taste, such as in salt; odor, such as in sulfur; florescence under an ultraviolet light; or magnetism. Vinegar is used for testing lime minerals such as calcite because the acid reacts with the carbonate, causing the surface to fizz and bubble.

Ore and mineral deposits are natural concentrations of useful metals, minerals or rocks, which can be economically exploited. Concentrations that are too small or too low-grade for mining are called occurrences or mineralizations. It is very important to understand the economic implications of the difference between these terms. Unfortunately, their wrong application is

common and leads to fundamentally misleading deductions. Therefore, the denomination "economic ore deposit" may be used when a clear attribution to this class is to be emphasized. Note that not all ores are strictly natural – it is very commonthat waste of a former miners' generation is today's profitable ore, such as tailings of earlier gold, copper and diamond mining. Mineral deposits are basically just valuable

rocks. Their formation is compared with processes that have produced ordinary rocks and is investigated with petrological methods (Robb 2005). Mineral deposits can also be thought of as a geochemical enrichment of elements or compounds in the Earth's crust, which is determined by their chemical properties (Railsback 2003; Lehmann et al. 2000b). The ratio between the content of a valued element in an ore deposit and its crustal average (Clarke values, Wedepohl 1995) is called the "concentration factor". Formation of iron ore, with today's typical grade of 60% Fe relative to an average crustal iron concentration of ~5%, requires 12-fold concentration. Copper ore that has 1% Cu compared to the crustal average of 0.007% Cu in the crust exhibits a 140-fold enrichment. Gold ore with 10 grams/tonne "distilled" from ordinary rocks with 0.002 g/t Au attests to a 5000-fold concentration.

Manifold are the processes and factors leading to the concentration of elements and minerals, including the formation of mineral deposits (Robb 2005). Final causes are the dynamic interactions between the Earth's core, mantle and crust, and of the hydro-, bio- and atmosphere. Cooling and

devolatilization of the Earth and unmixing of the system in the geological-geochemical cycle and during the transfer of elements have important roles (Lehmann et al. 2000b). With reference to the origin, endogenous and exogenous process systems are distinguished. The first are those resulting from the dynamics of the Earth's interior that are ultimately driven by the Earth's heat flow. At present, the total heat flow at the Earth's surface is $46\pm3$ Terawatts ($10^{12}$ J/s), resulting from heat entering the mantle from the core, of mantle cooling, radiogenic heating of mantle and crust by the decay of radioactive elements and of various minor processes (Lay et al. 2008). Exogenous processes take place at the Earth's surface and are mainly due to the flow of energy from the sun (~$12.10^{18}$ J/s). In rare cases, extraterrestrial processes have contributed to the formation of mineral deposits by impact of meteorites and asteroids.

The origin of mineral deposits is often due to a complex combination of several processes, boundary conditions and modifying factors, collectively making up the metallogenetic, or minerogenetic system. Evidence for such systems that operated in the geological past is always fragmentary. Some questions can possibly be answered by studying presently active ore-forming systems (e.g. black smokers in the deep oceans), but this method ("actualism") has limitations. Because of the unknown factors, there is often room for different interpretations (hypotheses) of the scientific facts. Economic geology strives to improve continuously the genetic models of ore formation, i.e. complete schemes of these systems. This effort is assisted by progress in many other sciences (from biology to physics), but the reverse is also true. Economic geology provides a fascinating insight into geological systems that are extremely rare and can only be illuminated by studying mineral deposits. The practical mission of economic geology is the provision of metals and minerals that society requires. Of course, this implies cooperation with other scientific, technical and financial professionals.

# Introduction to ore minerals. Principle ore minerals of Aluminum, Copper, Lead, Zinc, Antimony, Nickel, Tin, Chromium, Magnesium and Iron, their important properties, mode of formation, mode of occurrence, uses and distribution in India.

The **Mining industry in India** is a major economic activity which contributes significantly to the economy of India. The GDP contribution of the mining industry varies from 2.2% to 2.5% only but going by the GDP of the total industrial sector it contributes around 10% to 11%. Even mining done on small scale contributes 6% to the entire cost of mineral production. Indian mining industry provides job opportunities to around 700,000 individuals. As of 2012, India is the largest producer of sheet mica, the third largest producer of iron ore and the fifth largest producer of bauxite in the world. India's metal and mining industry was estimated to be $106.4bn in 2010.

*Major Minerals in India:*

India has vast deposit of minerals. Our metallic ores are very rich and of a very high quality. They are sufficient for maintaining most of our key industries. The major minerals produced in India are Iron-ore, Bauxite, Mica, Coal and Petroleum.

1. *Iron-ore*: Presently, India is ranked third in Iron ore production. A large quantity of world's iron ore reserves is possessed by India. Iron ore of very good quality (Haematite and Magnetite) is obtained from principal areas in Orissa and Singhbhum in Bihar.
   Besides these, iron ore is obtained from Durg in Madhya Pradesh and Salem in Tamil Nadu. Deposits of iron ore are also found in Karnataka. Iron-ore contributes a major share the total value of metallic minerals that is produced in India. It is also a good foreign exchange earner next only to tea, sugar, jute and cotton.
2. *Bauxite*: India is the fifth largest producer of Bauxite in the world. Bauxite is the ore of aluminium. Important bauxite deposits occur in Bihar, Goa, Gujrat, Jammu and Kashmir, Karnataka, Madhya Pradesh, Maharashtra, Orissa and Tamil Nadu. Bauxite deposits are exploited at Lohardaga in Ranchi district. Amarkantaka in Madhya Pradesh contains the largest deposit of bauxite.
3. *Mica*: India is one of the largest mica-producing countries of the world. India is ranked first in sheet mica production. The Bihar mica is of the very high quality. In India, the largest supply of Mica comes from Bihar. In Bihar the most important areas are Gaya and Hazaribagh in the 'mica belt' 150 km. long and 32 km. wide. Another important area is Nellore in Andhra Pradesh. The Nellore mica belt 100 km. long and 25 km wide. It is also obtained from Rajasthan. It is used in electrical industry. Due to poor development

of electrical industries at home, India exports most of the output contributing 75% of the world's requirements. Al-Bauxite, H—Hmenite, Pb-Zn-Lead-Zinc ore, Au-Gold, M—Mica, U—Uranium ore, Cr—Chromite, P—Rock Phosphate, Na—Salt, Cu—Copper Ore, Mg—Magnesite, R—Refractory mineral, Fe—Iron-Ore and Mn—Manganese Ore.

4. *Coal*: Coal is unevenly distributed in India. India is one of the principal producers of coal in the world. Bihar and West Bengal produce the largest quantity of coal in India and the quality is good. Jharia, Giridih, Bokaro, Karanpura, etc. in Bihar and Raniganj in West Bengal are the most important mining centers. Besides these areas, coal is found at Talcher in Orissa, Tendur and Singareni in Andhra Pradesh, Pench Valley and Umaria in Madhya Pradesh, Bihar along supplies 44% of India's total output.

5. *Petroleum*: India is poor in petroleum resources. Assam has the oldest oilfields at Digboi, Naharkatia, Moran, etc. These oil-fields are situated in the north-eastern part of Assam. The important new oil-fields are at Lunej, Ankleshwer, Kalol—all near the Gulf of Cambay in Gujrat and the Bombay high offshore oil field.

6. *Other Minerals*: Coppor-ore, diamond, graphite, chromite ($FeCr_2O_4$), lead, magnesite (($MgCO_3$), manganese-ore, etc. are other mineral products of India. Besides these, sand and lime are found in various parts of the country. They are widely used in glass-blowing industries.

## *Processes of Ore Formation*

Current theories of the genesis of ore deposit can be divided into internal (endogene) and external (exogene) or surface processes. It must be understood that more than one mechanism may be responsible for the formation of an ore body. Example - stockwork porphyry copper deposit at depth (epigenetic) with a syngenetic massive sulfide deposit at the surface. The Table at the end of the document summarizes the principal theories of ore genesis,

Depending upon whether an ore deposit formed at the time of and together with the enclosing rock, or was introduced into it by subsequent processes, they are classed as:

*Syngenetic* - A deposit formed at the same time as the rocks in which it occurs. Ex. Banded Iron Formation

*Epigenetic* - A deposit introduced into the host rocks at some time after they were deposited. Ex. Mississippi Valley-type Deposits

*Magmatic Deposits*: Those deposits, not including pegmatites that have formed by direct crystallization from a magma. Two types:

- *Fractional crystallization* - Any process whereby early formed crystals can not re-equilibrate with the melt. Includes 1) gravitative settling; 2) flowage differentiation; 3) filter pressing and 4) dilation. Number 1 is the most important and results from the settling of early formed crystals to the bottom of the magma chamber. Rocks formed in this manner are termed cumulates and are often characterized by rhythmic layering. In

ore deposits the alternating layers are often magnetite and/or chromite between layers of silicate. Ex. Bushveld igneous complex.

- Immiscible liquid - Typical example is oil and water. In ore deposits we deal with silicate and sulfide magmas. As a magma cools, sulfides coalesce as droplets and due to higher density settle out. Most common sulfides are iron sulfides, but nickel, copper and platinum also occur. Ex. Sudbury, Canada. The settling out of the heavier sulfides results in the peculiar net-textured ores often found in many of these deposits.

*Pegmatitic Deposits*:  Pegmatites are very coarse grained igneous rocks. Commonly form dike-like masses a few meters to occasionally 1-2 km in length. Economic ore deposits are associated with granitic pegmatites since felsic magmas carry more water. Residual elements such as Li, Be Nb, Ta, Sn and U that are not readily accommodated in crystallizing silicate phases end up in the volatile fraction. When this fraction is injected into the country rock a pegmatite is formed. Temperatures of deposition vary from 250-750°C. Pegmatites are divided into simple and complex. Simple pegmatites consist of plagioclase, quartz and mica and are not zoned. Complex have a more varied mineralogy and are strongly zoned. Crystals in pegmatites can be large, exceeding several meters. Three hypotheses to explain their formation:

a.    fractional crystallization
b.    deposition along open channels from fluids of changing composition
c.    crystallization of a simple pegmatite and partial to complete hydrothermal replacement

*Hydrothermal Deposits*:  Hot aqueous solutions are responsible for the formation of many ore deposits. Fluid inclusion research indicates most ore forming fluids range in temperature from 50°C to 650°C. Analysis of the fluid in inclusions has shown that water is the most important phase and salinities are often much greater than those of seawater. The chemistry of ore fluids and the mechanism of deposition of ore minerals remains a subject of hot debate. Arguments boil down to a) source and nature of the solutions b) means of transport of the metals and c) mechanism of deposition.

*Metamorphic/Metasomatic Deposits*:  Pyrometasomatic deposits (skarns) developed at the contact of plutons and host rock. Generally, host rock is a carbonate and new minerals formed are the calc-silicates diopside, andradite and wollastonite. Temperatures involved are thought to be 300-500°C, but pressure is probably quite low. Three stage process:

1.    Recrystallization
2.    Introduction of Si, Al, Fe, Mg
3.    Hydration and introduction of elements associated with volatile fraction

Other metamorphic processes are relatively unimportant, but hydration/dehydration during regional metamorphism may concentrate metals at the metamorphic front. Sodic metasomatism of K-spar is thought to have been important in the concentration of gold at Kalgoorlie. Conversion of feldspar from K-spar to Na plag resulted in the expulsion of gold which could no

longer be accommodated in the feldspar lattice. Skip over Mechanical-chemical sedimentary processes since they are covered in the other course.

*Volcanic Exhalative Deposits*:  Some ore deposits often show spatial relationships to volcanic rocks. They are conformable with the host and frequently banded suggesting sedimentary processes. Principal constituent is pyrite with lesser chalcopyrite, aphalerite, galena, barite and Ag-Au. These were thought until the late 60's to be epigenetic, but it is now realized they are syngenetic. They show a progression of types with three distinct end members:

1. *Cyprus type* - Associated with mafic volcanics and ophiolite sequences. Found in spreading centers and back arc basins. Consist predominantly of pyrite with lesser chalcopyrite. Typified by the Cyprus pyrite-cu ores.

2. *Besshi type* - Associated with basaltic to dacitic volcanism. Thought to form during the initial stages of island arc formation. Many Besshi type deposits occur in Precambrian rocks and these may have been generated in entirely different tectonic settings. Pyrite dominant, but chalcopyrite and sphalerite very common. Typified by many of the volcanogenic deposits of Canada.

3. *Kuroko type* - Associated with dacitic to rhyolitic volcanics. Form during the waning stages of island arc volcanism. Pyrite occurs, but is not dominant Usually galena or sphalerite are predominate with lesser chalcopyrite and tetrahedrite. Also significant silver in this type. Typified by the Kuroko deposits.

Although it is agreed ores are associated with volcanism the source of the ore bearing solutions continues to be debated. Many feel ore fluids are of magmatic origin, but others feel they are merely convecting seawater.

## Important properties, mode of formation, mode of occurrence, uses

*Aluminum* - The ore is mined from rocks that have been exposed to weathering in a tropical environment, bauxite. The main ore minerals in bauxite are gibbsite, bohmeite, and diaspore.

*Uses*

- Transportation (automobiles, aircraft, trucks, railway cars, marine vessels, bicycles, spacecraft, etc.) as sheet, tube, and castings.
- Packaging (cans, foil, frame of etc.).
- Food and beverage containers, because of its resistance to corrosion.
- Construction (windows, doors, siding, building wire, sheathing, roofing, etc.).
- A wide range of household items, from cooking utensils to baseball bats and watches.
- Street lighting poles, sailing ship masts, walking poles.
- Outer shells and cases for consumer electronics and photographic equipment.

- Electrical transmission lines for power distribution ("creep" and oxidation are not issues in this application as the terminations are usually multi-sided "crimps" which enclose all sides of the conductor with a gas-tight seal).
- MKM steel and Alnico magnets.
- Super purity aluminium (SPA, 99.980% to 99.999% Al), used in electronics and CDs, and also in wires/cabling.
- Heat sinks for transistors, CPUs, and other components in electronic appliances.
- Substrate material of metal-core copper clad laminates used in high brightness LED lighting.
- Light reflective surfaces and paint.
- Pyrotechnics, solid rocket fuels, and thermite.
- Production of hydrogen gas by reaction with hydrochloric acid or sodium hydroxide.
- In alloy with magnesium to make aircraft bodies and other transportation components.
- Cooking utensils, because of its resistant to corrosion and light-weight.
- Coins in such countries as France, Italy, Poland, Finland, Romania, Israel, and the former Yugoslavia struck from aluminium or an aluminium-copper alloy.
- Musical instruments. Some guitar models sport aluminium diamond plates on the surface of the instruments, usually either chrome or black. Kramer Guitars and Travis Bean are both known for having produced guitars with necks made of aluminium, which gives the instrument a very distinctive sound. Aluminium is used to make some guitar resonators and some electric guitar speakers

*Copper* - Most copper ore bodies are mined from minerals created by weathering of the primary copper ore mineral chalcopyrite. Minerals in the enriched zone include chalcocite, bornite, djurleite. Minerals in the oxidized zones include malachite, azurite, chyrsocolla, cuprite, tenorite, native copper and brochantite.

*Uses*

Historically, copper was the first metal to be worked by people. The discovery that it could be hardened with a little tin to form the alloy bronze gave the name to the Bronze Age. Traditionally it has been one of the metals used to make coins, along with silver and gold. However, it is the most common of the three and therefore the least valued. All US coins are now copper alloys, and gun metals also contain copper. Most copper is used in electrical equipment such as wiring and motors. This is because it conducts both heat and electricity very well, and can be drawn into wires. It also has uses in construction (for example roofing and plumbing), and industrial machinery (such as heat exchangers). Copper sulfate is used widely as an agricultural poison and as an algicide in water purification. Copper compounds, such as Fehling's solution, are used in chemical tests for sugar detection.

Copper metal does occur naturally, but by far the greatest source is in minerals such as chalcopyrite and bornite. Copper is obtained from these ores and minerals by smelting, leaching and electrolysis. The major copper-producing countries are Chile, Peru and China.

*Iron* - Two major minerals in the production of iron are it's oxides, hematite and magnetite. These are found in pre-Cambrian iron formations. Historically there was also production from goethite and siderite. The iron sulfides (pyrite and pyrrhotite) were not used as iron sources due

to the difficulty of removing sulfur from the metals and the brittleness this sulfur caused in the metal.

*Uses*

Iron is pretty common in our new world. It can be found everywhere. It is not only included in the makeup of different transport options. It is also included in many different products, items, and things that run our modern world. The reason iron is used in many ways is because it has properties that can be changed according to the need of mankind by mixing it with other substances – either metallic or nonmetallic. There are many different types of steels available today. Each type is made with iron combined with different elements including carbon, silicon, and nickel among others. Steel is an important component in every structure, in every type of construction. That's why everywhere you go, everywhere you look, you will find iron at work. Buildings, bridges, skyscrapers, and other types of construction would not be complete if it does not include iron in its framework. That's the same thing with automobiles, aircrafts, ships, heavy carriers, and heavy machineries.

*Lead* - The primary ore mineral for lead is it's sulfide - galena. Some minor production from the past has come from secondary lead minerals - cerussite and anglesite.

*Uses*

This easily worked and corrosion-resistant metal has been used for pipes, pewter and paint since Roman times. It has also been used in lead glazes for pottery and, in this century, insecticides, hair dyes and as an anti-knocking additive for petrol. All these uses have now been banned, replaced or discouraged as lead is known to be detrimental to health, particularly that of children. Lead is still widely used for car batteries, pigments, ammunition, cable sheathing, weights for lifting, weight belts for diving, lead crystal glass, radiation protection and in some solders. It is often used to store corrosive liquids. It is also sometimes used in architecture, for roofing and in stained glass windows.

*Zinc* - The primary zinc ore mineral is sphalerite, zinc sulfide. Some past production has been from smithsonite and hemimorphite.

*Uses*

Most zinc is used to galvanise other metals, such as iron, to prevent rusting. Galvanised steel is used for car bodies, street lamp posts, safety barriers and suspension bridges.

Large quantities of zinc are used to produce die-castings, which are important in the automobile, electrical and hardware industries. Zinc is also used in alloys such as brass, nickel silver and aluminium solder. Zinc oxide is widely used in the manufacture of very many products such as paints, rubber, cosmetics, pharmaceuticals, plastics, inks, soaps, batteries, textiles and electrical equipment. Zinc sulfide is used in making luminous paints, fluorescent lights and x-ray screens.

*Antimony* - The primary ore of antimony is it's sulfide, stibnite.

*Uses*

Antimony is used in the electronics industry to make some semiconductor devices, such as infrared detectors and diodes. It is alloyed with lead or other metals to improve their hardness and strength. A lead-antimony alloy is used in batteries. Other uses of antimony alloys include

type metal (in printing presses), bullets and cable sheathing. Antimony compounds are used to make flame-retardant materials, paints, enamels, glass and pottery.

*Nickel* - The primary nickel ores are pentlandite, nickel bearing pyrrhotite and a weathering product, garnierite (a mixture of népouite, pecoraite and willemseite).
*Uses*
Nickel resists corrosion and is used to plate other metals to protect them. It is, however, mainly used in making alloys such as stainless steel. Nichrome is an alloy of nickel and chromium with small amounts of silicon, manganese and iron. It resists corrosion, even when red hot, so is used in toasters and electric ovens. A copper-nickel alloy is commonly used in desalination plants, which convert seawater into fresh water. Nickel steel is used for armour plating. Other alloys of nickel are used in boat propeller shafts and turbine blades. Nickel is used in batteries, including rechargeable nickel-cadmium batteries and nickel-metal hydride batteries used in hybrid vehicles. Nickel has a long history of being used in coins. The US five-cent piece (known as a 'nickel') is 25% nickel and 75% copper. Finely divided nickel is used as a catalyst for hydrogenating vegetable oils. Adding nickel to glass gives it a green colour.

*Tin* - Primary ore is cassiterite. Tin is generated via the long S-process in low-to-medium mass stars (with masses of 0.6 to 10 times that of Sun), and finally by beta decay of the heavy isotopes of indium. Tin is the 49th most abundant element in Earth's crust, representing 2 ppm compared with 75 ppm for zinc, 50 ppm for copper, and 14 ppm for lead.
Cassiterite ($SnO_2$) is by far the most important tin ore, although small amounts of tin are recovered from sulphide minerals such as stannite ($Cu_2FeSnS_4$). Tin occurs in both primary and secondary deposits. Primary deposits are typically associated with granite intrusive rocks which form when magma bodies are embodied into rock beneath the earth's surface, rather than on it as in the case of volcanic rock. Primary deposits can occur within the granite or within pegmatities or aplites (dyke like rocks) associated with the granite. They occur also in rocks surrounding the margins of the intrusive rocks as veins, disseminations, skarns or carbonate replacements generated by tin bearing fluids derived from the granite magmas. Secondary deposits (placers) derive from the weathering and erosion of primary tin deposits. Cassiterite is chemically resistant, heavy and readily forms residual concentrations. These concentrations may develop over a primary deposit (eluvial) and on slopes below the deposit (colluvial). When the cassiterite reaches a drainage system, it may be transported to a river channel and concentrated into an alluvial placer deposit. A placer deposit buried by younger sediments or lava is known as a deep lead. Deposits in oceanic submerged river channels are important sources of tin. More than half of the world's tin production is from deposits such as these, mainly in Malaysia, Indonesia and Thailand.
*Uses*
Tin has many uses. It takes a high polish and is used to coat other metals to prevent corrosion, such as in tin cans, which are made of tin-coated steel. Alloys of tin are important, such as soft solder, pewter, bronze and phosphor bronze. A niobium-tin alloy is used for superconducting magnets. Most window glass is made by floating molten glass on molten tin to produce a flat surface. Tin salts sprayed onto glass are used to produce electrically conductive coatings.

The most important tin salt used is tin(II) chloride, which is used as a reducing agent and as a mordant for dyeing calico and silk. Tin(IV) oxide is used for ceramics and gas sensors. Zinc stannate ($Zn_2SnO_4$) is a fire-retardant used in plastics. Some tin compounds have been used as anti-fouling paint for ships and boats, to prevent barnacles. However, even at low levels these compounds are deadly to marine life, especially oysters. Its use has now been banned in most countries.

*Magnesium* - Although magnesium is found in many minerals, only dolomite, magnesite, brucite, carnallite, and olivine are of commercial importance. Magnesium and other magnesium compounds are also produced from seawater, well and lake brines and bitterns.
*Uses*
Magnesium is one-third less dense than aluminium. It improves the mechanical, fabrication and welding characteristics of aluminium when used as an alloying agent. These alloys are useful in aeroplane and car construction. Magnesium is used in products that benefit from being lightweight, such as car seats, luggage, laptops, cameras and power tools. It is also added to molten iron and steel to remove sulfur.

As magnesium ignites easily in air and burns with a bright light, it's used in flares, fireworks and sparklers. Magnesium sulfate is sometimes used as a mordant for dyes. Magnesium hydroxide is added to plastics to make them fire retardant. Magnesium oxide is used to make heat-resistant bricks for fireplaces and furnaces. It is also added to cattle feed and fertilisers. Magnesium hydroxide (milk of magnesia), sulfate (Epsom salts), chloride and citrate are all used in medicine. Grignard reagents are organic magnesium compounds that are important for the chemical industry.

*Chromium* - The chief source is the mineral chromite which is found in large layered intrusives and serpentine bodies.
*Uses*
Chromium is used to harden steel, to manufacture stainless steel (named as it won't rust) and to produce several alloys. Chromium plating can be used to give a polished mirror finish to steel. Chromium-plated car and lorry parts, such as bumpers, were once very common. It is also possible to chromium plate plastics, which are often used in bathroom fittings. About 90% of all leather is tanned using chrome. However, the waste effluent is toxic so alternatives are being investigated.

Chromium compounds are used as industrial catalysts and pigments (in bright green, yellow, red and orange colours). Rubies get their red colour from chromium, and glass treated with chromium has an emerald green colour.

# Study of Refractory minerals, coal and petroleum.

## *Coal*

Coal is a flammable black hard rock used as a solid fossil fuel. It is mainly made up of 65-95% carbon and also contains hydrogen, sulphur, oxygen and nitrogen. It is a sedimentary rock formed from peat, by the pressure of rocks laid down later on top. The harder forms of coal, such as anthracite, are metamorphic rocks because they were changed by higher temperature and pressure.

Peat, and therefore coal, is formed from the remains of plants which lived millions of years ago in tropical wetlands, such as those of the late Carboniferous period (the Pennsylvanian). A similar substance made from wood by heating it in an airless space is called charcoal.

Coal can be burned for energy or heat. About two-thirds of the coal mined today is burned in power stations to make electricity. Coal is becoming less popular in new power plants as less expensive and less polluting technologies such as natural gas and hydroelectricity take over.

Coal can be dry-distilled (heated in high temperature in a place where there is no oxygen) to produce coke. Coke is even better fuel than coal, and can be used in smelting to reduce metals from their ores.

Under suitable conditions, plant material is transformed step by step into

1. **Peat**, which has industrial importance as a fuel in some regions, for example, Ireland and Finland. In its dehydrated form, peat is a highly effective absorbent for fuel and oil spills on land and water
2. **Lignite** (brown coal) is the lowest rank of coal and is used as fuel for electric power generation. Jet is a compact form of lignite that is sometimes polished and has long been used as an ornamental stone.

3. **Sub-bituminous coal** is used as fuel for steam-electric power generation. Also, it is a source of light aromatic hydrocarbons for thechemical synthesis industry.
4. **Bituminous coal** is a dense rock, black but sometimes dark brown. It is a relatively soft coal that breaks and burns readily and quickly. It used as fuel in steam-electric power generation, and for heat and power applications in manufacturing; also and to makecoke
5. **Steam coal** was once widely used as a fuel for steam locomotives. In this specialized use it is sometimes known as *sea-coal* in the U.S.[1] Small steam coal (*dry small steam nuts* or DSSN) was used as a fuel for domestic water heating
6. **Anthracite** is the highest quality: a harder, glossy, black coal. It is longer burning, and used mainly for residential and commercialspace heating.
7. Graphite is difficult to ignite and is not so commonly used as fuel: it was mostly used in pencils and, when powdered, as a lubricant.

Diamond is commonly believed to be the highest grade, but this is not true. Diamond is carbon but is not formed from coal. Coal contains impurities. The particular impurities determine the use. Coking coal has little ash or sulfur or phosphorus. Those would spoil the iron made by the blast furnace.

Since 1983 the world top coal producer has been China. In 2011 China produced 3,520 millions of tonnes of coal – 49.5% of 7,695 millions tonnes world coal production. In 2011 other large producers were United States (993 millions tonnes), India (589), European Union (576) and Australia (416). In 2010 the largest exporters were Australia with 328 million tonnes (27.1% of world coal export) and Indonesia with 316 millions tonnes (26.1%), while the largest importers were Japan with 207 million tonnes (17.5% of world coal import), China with 195 million tonnes (16.6%) and South Korea with 126 million tonnes (10.7%).

## *Petroleum*

Petroleum, along with oil and coal, is classified as a fossil fuel. Fossil fuels are formed when sea plants and animals die, and the remains become buried under several thousand feet of silt, sand or mud. Fossil fuels take millions of years to form and therefore petroleum is also considered to be a non-renewable energy source. Petroleum is formed by hydrocarbons (a hydrocarbon is a compound made up of carbon and hydrogen) with the addition of certain other substances, primarily sulphur. Petroleum in its natural form when first collected is usually named crude oil, and can be clear, green or black and may be either thin like gasoline or thick like tar.

There are several major oil producing regions around the globe. The Kuwait and Saudi Arabia's crude oil fields are the largest, although Middle East oil from other countries in the region such as Iran and Iraq also make up a significant part of world production figures. The North Sea crude oil fields are still fairly full, and are arguably the second most influential oil field in economic terms. Texas, once the world's major oil region, is now almost completely dry Petroleum is also a major part of the chemical makeup of many plastics and synthetics. Possibly the most startling usage of petroleum for many people is its appearance in foodstuffs such as beer and in medications such as aspirin. The world has a limited supply of petroleum, and current estimations tell us that within the next few decades mankind will have completely depleted this valuable natural resource. Although measures have been taken to ensure that there are cheap,

renewable fuel options in place for the eventuality it is still obvious that mankind faces a serious problem when petroleum supplies finally run out.

Petroleum is a fossil fuel derived from ancient fossilized organic materials, such as zooplankton and algae. Vast quantities of these remains settled to sea or lake bottoms, mixing with sediments and being buried under anoxic conditions. As further layers settled to the sea or lake bed, intense heat and pressure build up in the lower regions. This process caused the organic matter to change, first into a waxy material known as kerogen, which is found in various oil shales around the world, and then with more heat into liquid and gaseous hydrocarbons via a process known as catagenesis. Formation of petroleum occurs from hydrocarbon pyrolysis in a variety of mainly endothermic reactions at high temperature and/or pressure.

*Uses:*

The chemical structure of petroleum is heterogeneous, composed of hydrocarbon chains of different lengths. Because of this, petroleum may be taken to oil refineries and the hydrocarbon chemicals separated by distillation and treated by other chemical processes, to be used for a variety of purposes. The total cost of a plant is about 9 billion dollars per plant.

- The most common distillation fractions of petroleum are fuels.

Certain types of resultant hydrocarbons may be mixed with other non-hydrocarbons, to create other end products:

- *Alkenes* (olefins), which can be manufactured into plastics or other compounds
- *Lubricants* (produces light machine oils, motor oils, and greases, adding viscosity stabilizers as required)
- *Wax*, used in the packaging of frozen foods, among others
- *Sulfur or sulfuric acid*. These are useful industrial materials. Sulfuric acid is usually prepared as the acid precursor oleum, a byproduct of sulfur removal from fuels.
- *Bulk tar*
- *Asphalt*
- *Petroleum coke*, used in speciality carbon products or as solid fuel
- *Paraffin wax*
- *Aromatic petrochemicals* to be used as precursors in other chemical production

- Since the 1940s, agricultural productivity has increased dramatically, due largely to the increased use of energy-intensive mechanization, fertilizers and pesticides.

*Petroleum industry*

The petroleum industry is involved in the global processes of exploration, extraction, refining, transporting (often with oil tankers and pipelines), and marketing petroleum products. The largest volume products of the industry are fuel oil and gasoline. Petroleum is also the raw material for many chemical products, including pharmaceuticals, solvents, fertilizers, pesticides, and plastics.

### *Refractory minerals*

Refractory minerals can be defined as minerals or synthetic inorganic crystal phases that have high melting points. They should also be resistant to deformation and to softening at high temperatures. Even though their primary function is resistance to elevated temperatures; in many applications they must resist other destructive forces, such as chemical corrosion and abrasion .

Refractories are usually classified as acid, basic, or other. "Acid refractories" are mainly composed of silica or alumina-silica minerals. "Basic refractories" are produced from alkaline-earth oxides, such as *dolomite*, magnesia, lime, and magnesia-chrome ore mixtures.

#### *Acidic refractories*

Acidic refractories consist of mostly acidic materials like alumina ($Al_2O_3$) and silica ($SiO_2$). They are generally not attacked or affected by acidic materials, but easily affected by basic materials. They include substances such as silica, alumina, and fire clay brick refractories. Notable reagents that can attack both alumina and silica are hydrofluoric acid, phosphoric acid, and fluorinated gases (e.g. HF, F2). At high temperatures, acidic refractories may also react with limes and basic oxides.

#### *Neutral refractories*

These are used in areas where slags and atmosphere are either acidic or basic and are chemically stable to both acids and bases. The main raw materials belong to, but are not confined to, the $R_2O_3$ group. Common examples of these materials are alumina ($Al_2O_3$), chromia ($Cr_2O_3$) and carbon.

#### *Basic refractories*

These are used in areas where slags and atmosphere are basic; they are stable to alkaline materials but could react with acids. The main raw materials belong to the RO group to which magnesia (MgO) is a very common example. Other examples include dolomite and chrome-magnesia. For the first half of the twentieth century, the steel making process used artificial periclase (roasted magnesite) as a lining material for the furnace.

#### *Based on method of manufacture*

1. Dry press process
2. Fused cast
3. Hand molded
4. Formed (normal, fired or chemically bonded)
5. Un-formed (monolithic-plastic, ramming and gunning mass, castables, mortars, dry vibrating cements.)
6. Un-formed dry refractories.