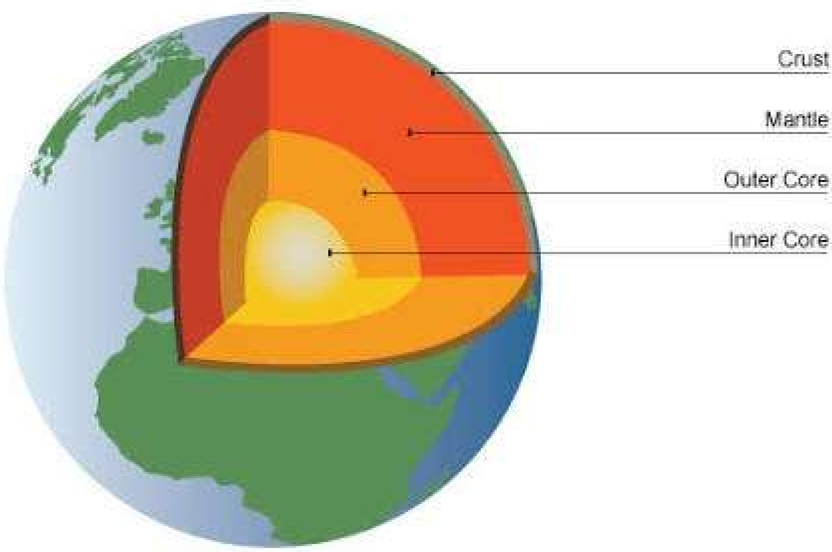
UNIT – I

ROCKS AND MINERALS

Syllabus: Disciplines involved in Engineering Geology, formation of minerals, physical properties of minerals, classification of minerals – Origin and occurrence of Igneous, Sedimentary and Metamorphic rocks – texture, structure, forms of Igneous rocks, Sedimentary rocks and Metamorphic rocks.



Disciplines involved in engineering geology:

a) **Physical Geology**

It deals with the origin, development and ultimate fate of various surface features of the earth and also with its internal structure. The role played by internal agents and external agent on the physical features of the earth makes major areas of study in physical geology. Similarly, the disposition of rock bodies, water bodies and huge moving deposits of ice on the surface and their structures also form important subjects of physical geology.

(b) **Geomorphology**

It deals specifically with the study of surface features of the earth, primarily of the land surface. Detailed investigations regarding development and disposition of mountains, plains, plateaus, valleys and basins and various other landforms associated with them; fall in the domain of geomorphology. The structure and evolution of these landforms through space and time are advanced fields of study within geomorphology.

(c) **Mineralogy**

Mineralogy is that branch of geology, which, deals with formation, occurrence, aggregation, properties, and uses of minerals. Mineralogy is sometimes itself divided into specific sub-branches such as crystallography, optical mineralogy and descriptive mineralogy, and so on. Crystallography is a well-established branch of mineralogy that deals exclusively with internal structure and external manifestations of minerals occurring in crystallized form in the natural process or made from synthetic processes.

(d) **Petrology**

Minerals occurring in natural aggregated form are called rocks; these rocks form the building blocks that make up the crust of the earth. The rocks are themselves made up of minerals already defined as building units. Formation of various types of rocks, their mode of occurrence, composition, textures and structures, geological and geographical distribution onthe earth are all studied under petrology. It is one of the most important subdivisions of geology and is further subdivided into three distinct branches: Igneous petrology, Sedimentary petrology and metamorphic petrology.

e) Historical Geology

It deals with the past history of the Earth as deciphered from the study of rocks and features associated with them. Rocks may be treated as pages of the Earth's history. They contain within them enough evidence indicative of nature and time of their formation, composition, constitution, magnetism, structural disposition and in many cases, fossils (remains of ancient life), all of which when interpreted scientifically reveal a lot about the events that have passed since their formation. Thus, fairly accurate estimates can be made from the above evidence about the climates, biological and environmental conditions prevailing just before, during and after the formation of these rocks in and around the areas of their occurrence Paleo-geography, paleontology and stratigraphy are three distinct subdivisions of Historical Geology.

f) Structural geology:-

Structural geology is the study of the three-dimensional distribution of rock units with respect to their deformational histories. The primary goal of structural geology is to use measurements of present-day rock geometries to uncover information about the history of deformation (strain) in the rocks, and ultimately, to understand the stress field that resulted in the observed strain and geometries. This understanding of the dynamics of the stress field can be linked to important events in the geologic past; a common goal is to understand the structural evolution of a particular area with respect to regionally widespread patterns of rock deformation (e.g., mountain building, rifting) due to plate tectonics.

g) Engineering geology:-

Engineering geology is the application of the geology to engineering study for the purpose of assuring that the geological factors regarding the location, design, construction, operation and maintenance of engineering works are recognized and accounted for. Engineering geologists provide geological and geotechnical recommendations, analysis, and design associated with human development and various types of structures. The realm of the engineering geologist is essentially in the area of earth-structure interactions, or investigation of how the earth or earth processes impact human made structures and human activities.

MINERAL:

Minerals are the building blocks of rocks. A mineral

- is a naturally occurring inorganic crystalline solid
- has an ordered internal arrangement of atoms
- has specific physical properties that are either fixed or that vary within some defined range.
- has a definite chemical composition that may vary within specific limits

Formation of minerals:

The processes involved in the genesis of minerals are

i) Solidification: Hot molten magma solidifies through cooling

ii) Sublimation: The gaseous form of minerals are formed through evaporation and precipitation

iii) Evaporation: Materials dissolved in water crystallize on precipitation

iv) Recrystallization: Minerals are formed due to recrystallization during metamorphism.

Solidification: Magma is a natural hot melt solidifies through cooling leading to the formation minerals known as solidification. This process is also called as crystallization. The composition and physical properties of minerals thus formed are governed by the rate of cooling and surrounding geological environment of magma. Since the earth's crust is made dominant of alumino-silicates most minerals formed are rich in silica & feldspar.

Sublimation: This process is generally associated with volcanism. In the process of sublimation, the mineral is formed through evaporation and precipitation directly from gaseous state, because of the sudden cooling of the vapors emanating from volcanoes. Since the emanating gases are about 2% of magma, very little minerals are derived from it. It is a rare process.

Recrystallization: It is a phenomenon which the mineral grains which have been already crystallized are placed for recrystallization due to changes in temperature and pressure (Metamorphism).

Evaporation: In this process, the materials dissolved in water solution precipitate under suitable environmental conditions.

PHYSICAL PROPERTIES OF MINERALS:

Physical properties of minerals can be identified by inspection of hand-held specimens in the field or by studying their optical properties by a polarized microscope. These physical properties are mainly used to identify and differentiate minerals.

i) Hardness:

- Hardness is the ability of a mineral to resist abrasion or scratching on its surface.
- One way geologists measure hardness is using a relative scale referred to as Moh's scale of mineral hardness which ranks 10 common minerals along a scale from 1-10 (1 refers to the softest minerals while 10 refers to the hardest mineral).
- Geologists measure a mineral's hardness by scratching the surface of mineral using minerals of known hardness, or by scratching the surface using a variety of other hardness indicators such as fingernails or glass.

ii) Luster:

- Luster refers to how light is reflected from the surface of a mineral.
- There are two main types of luster: metallic and non-metallic:

a) Minerals with a metallic luster are described as shiny, silvery, or having a metal-like reflectance.

b) Non-metallic minerals may be described as resinous, translucent, pearly, waxy, greasy, silky, vitreous/glassy, dull, or earthy

- Luster may be subjective, and thus is not always a reliable identifier

In non-metallic luster there are different types

a) Vitreous: Mineral resembles the luster of broken glass. Ex: quartz
b) Pearly: Luster exhibited by pearls. Ex: Muscovite
c) Resinous: Minerals exhibit luster like resin. Ex: Sphalerite
d) Earthy: Mineral has no shine but looks like dull. Ex: kaolin

iii) Color:

- Mineral color is determined by how the crystals absorb and reflect light. Although color is easy to recognize, it is often misleading.

- Minerals, such as quartz, fluorite, halite, and calcite occur in a wide variety of colors, and other minerals, such as olivine, malachite, and amphibole have fairly distinctive colors.

- Variations in a mineral's color may be the result of impurities in the atomic structure of the crystal or the presence of a particular chemical when the crystal formed.

- Because some minerals can occur in several colors, color is generally not a good characteristic for describing and identifying minerals.

iv) Streak:

- Streak refers to the color of a mineral's powdered form left behind after it is scraped or rubbed across a porcelain streak plate.

- A mineral may appear one color and then produce a streak with a different color.
- A mineral's streak color is a more reliable identification characteristic than the minerals perceived surface color.

v) Fracture:

- Fracture refers to the non-planar breakage of minerals.
- Minerals that break along fractures (as oppose to cleavage planes) do not exhibit predictable weakness along specified bonds.
- Fractures may be described as splintery, uneven, or conchoidal.

Even: Plane and smooth surface

Uneven: Rough surface

Splintery: Breaking in fibers

Conchoidal: Curved surfaces

v) Cleavage:

- Cleavage refers to the tendency of a mineral to break along planes of weakness in the chemical bonds, or along planes where bond strength is the least.
- Some minerals break along one dominant plane of cleavage producing parallel sheets, whereas others may break along two or more planes of cleavage, producing blocks or prism shapes.
- Not all minerals have distinct planes of weakness that produce cleavage, but those minerals that do, will consistently produce predictable cleavage planes.

a) One direction of cleavage (one plane): Mineral has single plane of weakness

Example: Micas (muscovite).

b) Two directions of cleavage (two planes): Mineral has the tendency to break in two directions.
Example: Feldspar

c) Three directions of cleavage (three planes)
Ex: Galena

d) Four directions of cleavage (four planes)
Ex: Fluorite

vii) Specific Gravity:

- Specific gravity refers to the weight or heaviness of a mineral, and it is expressed as the ratio of the mineral's weight to an equal volume of water.
- Water has a specific gravity of 1. Therefore, a mineral with a specific gravity of 1.5, is one and a half times heavier than water.
- Minerals with a specific gravity $\leq$ 2 are considered light, 2-4 are average, and >4.5 are heavy
- Specific gravity can be measured using complex lab tools such as the hydrostatic balance or more simple procedures involving beakers and water displacement measurements.

CLASSIFICATION OF MINERALS:

On the basis of application (or) use, minerals are broadly classified into two types.

1) Ore - forming minerals 2) Rock - forming minerals

The rock-forming minerals are those that are found in abundance in the rocks of the earth's crust while ore-forming minerals are not, but they have economical value.

1) Ore - forming minerals:
These minerals are formed from the solidification of magma (recrystallization). Sulphides of common elements occurring in rock –forming minerals are classified as ore- forming minerals. It may be noted that the economically exploitable minerals like galena, pyrite, chalcopyrite, etc., are also called ore-forming minerals.

2) Rock - forming minerals:
The great bulk of rocks of the Earth crust are formed by only a few minerals (not more than one hundred) and they are grouped together as rock forming minerals. Amongst these minerals, about 25 or so make up almost 99.5 percent of the rocks. Therefore, practical identification of most common rocks requires study a limited number of minerals making the job of a practicing engineer quite simple. Silicates, Oxides and

carbonates groups of minerals are the most common rock-forming minerals.

Formation of rocks: There are three types of rocks

1) Igneous rocks:

a) These are formed from the molten liquid minerals that lie below the Earth's crust. They're formed from magma that cools beneath the Earth's surface or from lava that cools upon the Earth's surface. These two methods of igneous rock formation are known as intrusive and extrusive, respectively.

b) Intrusive igneous formations can be forced to the surface of the Earth where they can exist as masses of rock known as plutons. The largest types of exposed plutons are called batholiths.

c) Slowly cooling igneous rock will usually contain larger mineral crystals than igneous rock that cools more quickly. The magma that forms igneous rock beneath the surface of the earth can take thousands of years to cool. Quickly cooling rock, often extrusive lava that comes from volcanoes or fissures in the Earth's surface has small crystals and may be quite smooth, such as the volcanic rock.

2) Sedimentary rocks:

a) Sedimentary rocks are formed by the lithification (cementing, compacting, and hardening) of existing rock or the bones, shells, and pieces of formerly living things. Rocks are weathered and eroded into tiny particles which are then transported and deposited along with other pieces of rock called sediments.

b) Sediments are cemented together and compacted and hardened over time by the weight and pressure of up to thousands of feet of additional sediments above them. Eventually, the sediments are lithified and become solid sedimentary rock. These sediments that come together are known as clastic sediments.

3) Metamorphic rocks:

a) Metamorphic rock, which comes from the Greek to "change form," is formed by applying great pressure and temperature to existing rock converting it into a new distinct type of rock. Igneous rocks, sedimentary rocks, and even other metamorphic rocks and be modified into metamorphic rocks.

b) Metamorphic rocks are usually created when they come under extreme pressure such as under many thousands of feet of bedrock or through being crushed at the junction of tectonic plates. Sedimentary rocks can become metamorphic rocks if the thousands of feet of sediments above them apply enough heat and pressure to further change the structure of the sedimentary rock.

c) Metamorphic rocks are harder than other types of rock so they're more resistant to weathering and erosion.

Forms of igneous rocks:

- **Intrusive igneous rocks** crystallize below Earth's surface, and the slow cooling that occurs there allows large crystals to form.
- **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.

Textures of igneous rocks:

The term texture mainly refers to the mutual relationships of the constituent minerals of a rock in addition to crystalline, granularity and shapes of minerals in a rock.

i) **Textures based on the degree of crystallinity**: Crystallization of different minerals takes place when the respective molecules in magma move to their centers of crystallization and arrange themselves in a definite pattern. Depending on the nature of cooling, the resulting igneous rocks are

a) Completely crystalline (holocrystalline) : Completely made up of minerals without any glassy matter, or

b) Completely Glassy (holohyaline): Composed of only glass without any minerals

c) Partly crystalline and partly glassy (hemi crystalline)

ii) **Textures based on granularity: I**n order for a crystal to form in 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.

a) For small degrees of under cooling, 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 ***phaneric texture***.

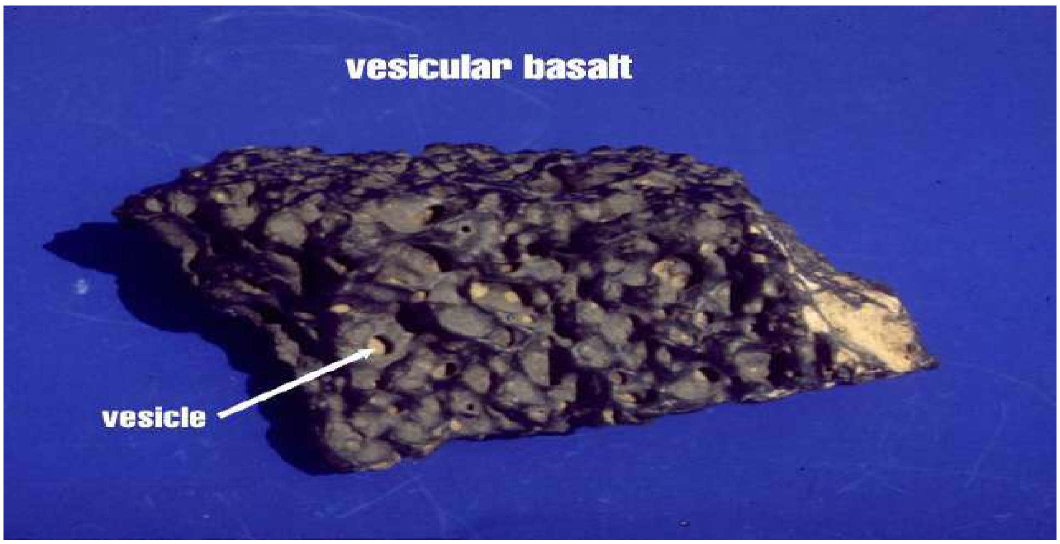
iii) **Textures based on mutual relations of constituent minerals of rock:** These textures are also genetically related and hence their study reveals the conditions of crystallization that had prevailed during their formation.

a) Equigranular texture: When magma or lava crystallizes under same conditions, equigranular texture develops. In this, the minerals present are approximately of the same size. Depending on the grain size this texture may be described either as phaneric or aphanitic.

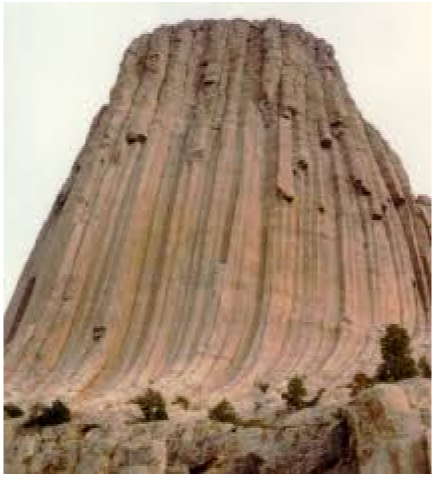
b) Inequigranular texture: Rocks having this type of texture are not composed of minerals of the same size. Some of inequigranular textures are porphyritic, poikilitic, ophitic textures.

Structures of igneous rocks: The common structures of igneous rocks are

1) **Vesicular structure**: When lava heavily charged with gases and other volatiles are erupted on the surface, the gaseous constituent's escapes from the magma as there is a decrease in the pressure. Thus, near the top of flows, empty cavities of variable dimensions are formed. The individual openings are known as vesicles and the structure as a whole is known as vesicular structure.



2) **Amygdaloidal structure**: If, however, the vesicles thus formed are subsequently filled in with some low-temperature secondary minerals, such as calcite, zeolite, chalcedony etc., these infillings are called 'amygdales'.
3) **Columnar structure:** As a consequence of contraction of lava due to cooling, a few sets of vertical joints develop. Such joints bring about the formation of columns, which may be square, rectangular, rhombic or hexagonal in outline.



4) **Sheet structure**: The development of one set of well defined joints sometimes brings about a slicing effect on the massive igneous rock body. If all such slices are horizontal, the structure is said to be sheet structure.

Another view of Enchanted Rock and its sheet structure.

5) **Pillow structure:** It consists of isolated pillow shaped masses piled one upon another... These are produced by extrusion of lava into rain-soaked air, beneath ice-sheets, under water logged sediments or in sea water.

2. Sedimentary Rocks Formation:

Sedimentary rock is formed by deposition and consolidation of mineral and organic material and from precipitation of minerals from solution. The processes that form sedimentary rock occur at the surface of the earth and within bodies of water. Rock formed from sediments covers 70-80 % of the earth’s land area, and includes common types such as limestone, chalk, sandstone, conglomerate and shale.

Mechanically formed: consisting of materials (gravels, sand, silt and clay) suspended in flowing water. The suspended materials are then deposited and consolidated. The mechanically formed sedimentary rocks are of three types:

- Rudaceous rocks which is the cementing together of boulders, for example, conglomerate.
- Arenaceous rocks for example sandstone,
- Argillaceous rocks which clay rocks for example shale
- Organically formed: Consisting of accumulated animals and plants remains. They are:
- Calcareous rocks, lime stone
- Carbonaceous rocks, coal
- Chemically formed: this type of rocks is formed by precipitation and accumulation of soluble constituents. These are Carbonate rocks, Limestone, dolomite, Sulphate rocks, Gypsum, Chloride rocks, salt
- **Textures of Sedimentary Rocks:**
- Sediment texture refers to the shape, size and three-dimensional arrangement of the particles that make up sediment or a sedimentary rock.
- Textures can be **clastic**, where they are composed of grains from pre-existing rocks (allochthonous grains) or **crystalline**, where the crystals (“grains” *sensu lato*) grew from a fluid producing an interlocking mosaic of crystals.
- Textures are **primary**, where the grains possess their arrangement that existed after they came to rest (or after precipitation in the case of crystals). In sedimentary rocks, however, textures are commonly **secondary**, because they have been altered in some way from their

original condition. The most common effect is compaction, where the weight of overlying sediments causes the component grains to rearrange themselves or even become fractured.

- **Shape:**

- Particle shape is difficult to quantify or describe. Shape is commonly described with reference to three axes at 90° to each other that can theoretically be placed inside any particle. The longest axis is *a*, shortest *c* and the intermediate is *b*. In a sphere or cube, those axes intersect at the centre and have equal length. By comparing the ratios of the axes, it is possible to describe four basic "shapes" of particles:
- The four main classes of grain shape, which are based upon the ratios of the long, intermediate and short diameters of any particle. Shape in some cases reflects erosional processes (how the rock broke up with weathering and transportation), but may also reflect structures and fabrics present in the parent rock. Shale, for example, will commonly produce flat particles, whereas quartzite (metamorphosed sandstone) may be more equant.
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- **Roundness** (or angularity):
- It refers to how smooth or sharp are the edges of particles. It is usually measured with reference to a comparative chart (The commonest is: Powers, M.C., 1953, a new roundness scale for sedimentary particles.
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- **Sediment Fabrics:**
- Sediment fabric stresses the three-dimensional make up of the components in the rock -- especially whether the particles show any preferred orientation, and how individual grains are in contact with each other. Primary fabrics are those that formed during sedimentation; secondary fabrics reflect the imprint of post-depositional processes such

as compaction by overlying younger sediments.

- Fabric can be useful in determining the depositional processes. If particles are elongate, they may be aligned by currents parallel to the direction of flow. A common fabric in gravel and conglomerate is **imbrication**.
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- **Grain Size:**
- Particles are generally measured by their maximum grain diameter. The most common classification is use is the Wentworth scale. In this classification, terms such as pebble, sand and gravel have well-defined limits. Many statistical methods can be applied to particle size distributions (e.g., median, mean, skewness, kurtosis, *etc.*) to try to characterize the depositional processes that produced them (e.g., wind, swash, etc.), and even to distinguish depositional environments. This was popular in the 1960s and 1970s, but is a rarer approach today.
- Different methods are required for determining grain size in loose (unconsolidated) sediment and sedimentary rock. Methods also vary with particle size range.

Metamorphic Rocks:

Metamorphic rocks form from pre-existing igneous, sedimentary and metamorphic rocks under the conditions of high temperature and pressure or through the action of chemical alteration induced by very hot and chemically aggressive pore water.

The original texture, composition and mineralogy of the parent rocks get changed in the new physic-chemical and/or tectonic conditions. The process responsible for this change is known as Metamorphism.

Metamorphic Process:

During metamorphism, a series of changes in texture and mineral composition of the rock occur due to readjustment to new environment conditions. Readjustment occurs because the minerals and pore fluids become unstable, and a new set of stable minerals or mineral assemblage will form under the new environment. Recrystallization, metasomatism, granulation and plastic deformation are the processes of metamorphism; the first two processes being the major ones.

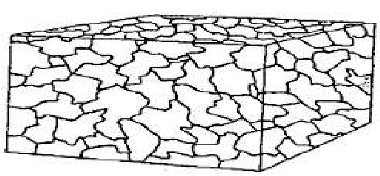
Metamophic Textures and Structures:

There are two basic types of texture for a metamorphic rock. Rocks which exhibit foliation are said to exhibit a planar or foliated texture. Planar texture can further be divided based on the type/degree of foliation. Rocks which do not show foliation are said to exhibit a granular or non-foliated texture. Metamorphic textures and structures distinguished on the basis of the size, shape and orientation of the crystals and foliation are presented below:

a) On the basis of size, shape and orientation of crystals:

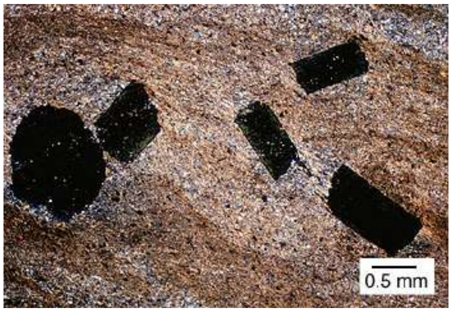
Some of the important types of textures are as follows.

- **Granoblastic**: This type of texture results from Recrystallization of minerals and is similar to the holycrystalline texture of igneous rocks. In a crystalloblastic metamorphic rock, the texture may be xenoblastic-none of the minerals appear to have perfect crystal outline; ideoblastic-mineral grains have developed perfect crystal outline; and Granoblastic-the minerals grains are equidimensional.



granoblastic texture

- **Porphyroblastic**: This type of texture is characterized by large crystals embedded in a fine grained groundmass. Porphyroblastic textures develop in a wide range of rock types and metamorphic environments when minerals in parent rock recrystallize to form new minerals. During Recrystallization, certain metamorphic minerals, including garnet, staurolite and andaulusite, invariably develop a small number of very large crystals. By contrast, minerals such as muscovite, biotite and quartz typically form a large number of very small grains.



- **Palimpsest**: when the remnant of the mineral composition and texture of the parent rock is preserved, the metamorphic texture is called palimpsest.

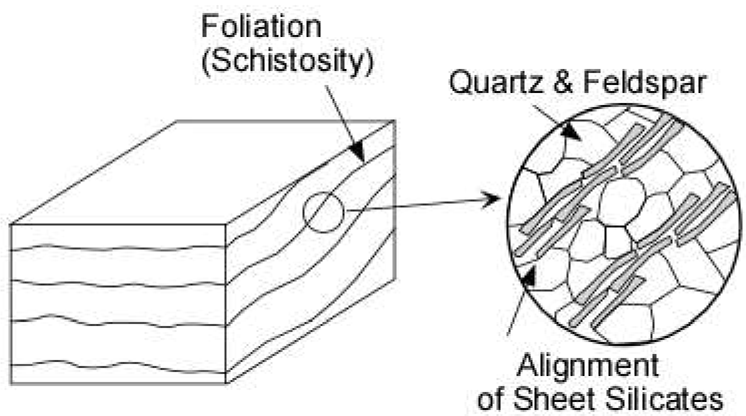
b) On the basis of foliation:

The texture is classed as foliated and non-foliated

During metamorphism, new textures are developed besides formation of new minerals. The most common of these textures of foliation. Foliation refers to any planar arrangement of mineral grains or structural features with in a rock. The layered texture means that the minerals are aligned and groove under directed pressure (compression stress). It is a fundamental characteristic of rock units that have been strongly folded and distorted. Under the changed conditions of temperature and pressure, new mineral grains as well as pre-existing minerals recrystallize, i.e. the grains grow and coarsen. Foliation comprises a segregation of particular minerals into different bands or contiguous lenticels that exhibit a common parallel orientation.

Rocks resulting from regional metamorphism generally display foliations. Examples of foliation include the parallel alignment of flattened mineral grains and pebbles; slaty cleavage where rocks can be easily split into thin, tabular slabs along parallel surfaces; the parallel alignment of platy and/or elongated minerals (schitosity); and compositional banding where the separation of dark and light minerals generate a layered appearance. These diverse types of foliation can form by

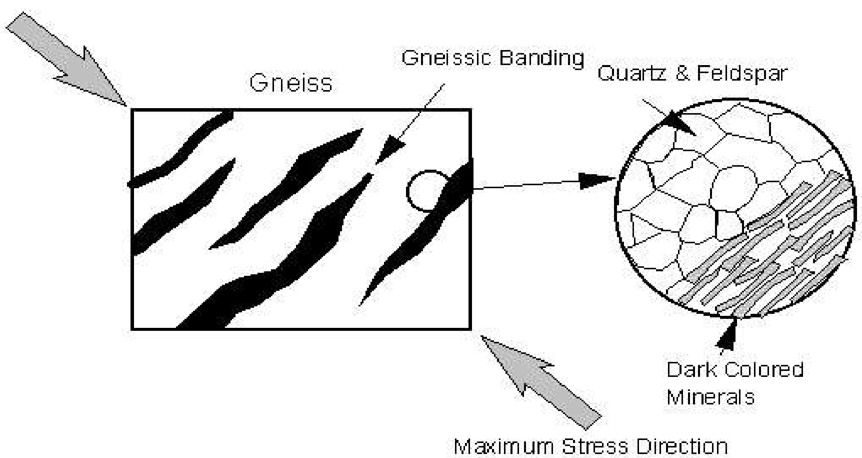
1. Rotation of platy and/or elongated mineral grains into a new orientation.
2. Recrystallization of minerals to form new grains growing in the direction of preferred orientation.
3. Changing the shape of equidimensional grains into elongated shapes that are aligned in a preferred orientation.



- **Slaty Cleavage:** Also known as rock cleavage, it is developed in most metamorphic rocks but slates are the best example, hence termed 'slaty cleavage'. It is probably the most familiar type of preferred orientation (particularly of those belonging to the mica family) and occurs in rocks of low metamorphic grade and is characteristic of slates and phyllites. It is independent of bedding.
- **Schistosity:** It develops in a rock when it is subjected to increased temperatures and stress that involves its reconstitution, which is brought about by localized solution of mineral material and Recrystallization. The minute mica and chlorite grains in slate begin to grow many times larger. When these platy minerals grow large enough to be discernible with the unaided eye and exhibit a planar or layered structure, the rock is said to exhibit schistosity. Rocks having this texture are referred to as schist.

In addition to platy minerals, schist often contains deformed quartz and feldspar grains that appear as flat, or lens-shaped, grains hidden among the mica grains. The more abundant, flaky and tabular minerals are in such rocks, the more pronounced is the schistosity. However, the schisotocity may disappear due to a change in high temperature and pressure and rock deformation.

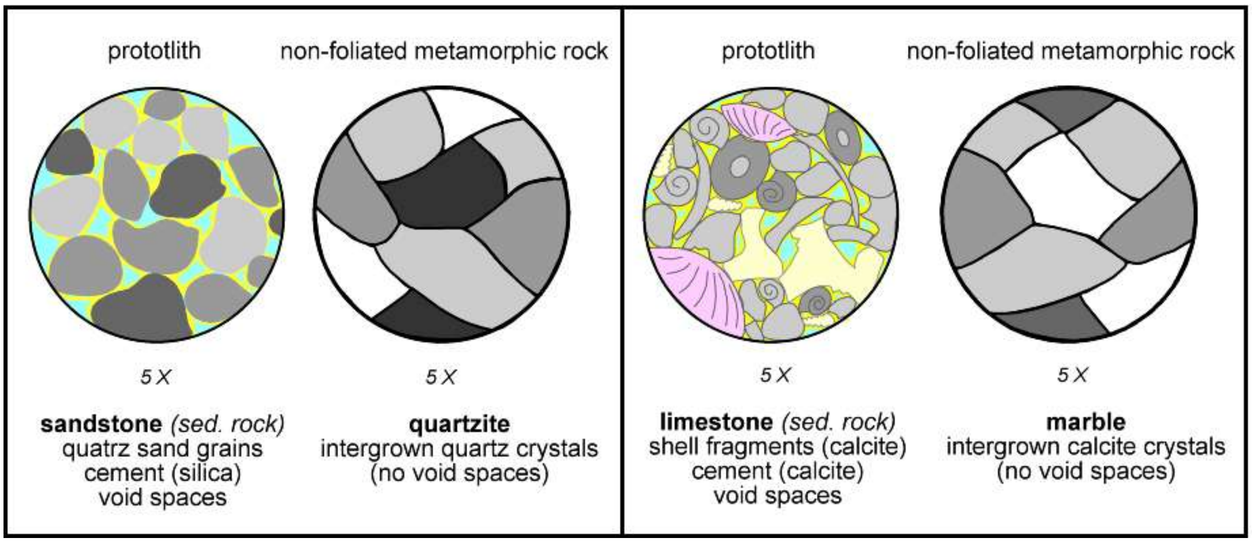
- **Gneissic texture:** during high-grade metamorphism, ion migrations can result in the segregation of minerals, giving the rock a banded appearance called gnesis texture. A metamorphic rock with this texture is called gnesis. Gnessis do not usually split as easily as slates and some schists. Gneisses that do cleave, tend to break parallel to their foliation and expose mica-rich surfaces that resemble schist.



Non-foliated texture:

Metamorphic rocks can only be foliated if the composition of their parent rocks allows mica formation; those that do not are referred to as non-foliated. Non-foliated metamorphic rocks typically develop in environments where deformation is minimal and the parent rocks are composed of minerals that exhibit equidimensional crystals, such as quartz or calcite. They are also known as granular metamorphic rocks.

Contact metamorphism and regional metamorphism of rocks that contain few platy minerals (e.g. mica and chlorite), produce rocks that do not display foliation. Some of the examples of such rocks are quartz sandstones transformed into quartzite, limestones transformed into marble and basalt transformed into amphibolite. Hornfels is another non-foliated, fine grained metamorphic rock. It occurs typically in metamorphic aureolas around intrusions (contact metamorphism).



Unit-II

Geomorphology and Structural Geology

Syllabus

Landforms and their classification, Lithology, Folds, Faults, Joints and Unconformities and their classification, Land subsidence, Classification and field identification of folds, faults using Satellite images.

Landforms

Landforms are natural features of the landscape, natural physical features of the earth's surface, for example, valleys, plateaus, mountains, plains, hills, glaciers.

Types of landforms

There are many different types of landforms on the Earth. Some of them were formed over millions of years and others were formed in a matter of hours. The formation of a mountain range, for example, would usually take a few million years. Events like earthquakes and volcanic eruptions can 'wipe off' landforms, or form new ones in a matter of hours. Examples of some natural landforms are mountains, oceans, rivers, hills, volcanoes, valleys, desserts, waterfalls, caves and cliffs. This chapter looks at the formation of some major types of landforms.

Mountains

A mountain is a raised part of the Earth's surface. Mountains can be formed in different ways that involve internal (inside) or external (outside) natural forces. The movement of tectonic plates is called plate tectonics. **Plate tectonics** is an internal natural force because it happens inside the Earth. When tectonic plates collide, they raise the Earth's crust. As mentioned before, tectonic plates move very slowly, so it takes many millions of years to build a mountain. Mountains can also be formed by external natural forces like rain, wind and frost in the process of erosion.

Mountains with shapes that are sharp and jagged are called young mountains. Mountains that have a smoother, more rounded look are called old mountains. The South American mountain range, the Andes, is a young mountain range. Old mountains look smoother because they have been shaped by natural weathering over a longer period of time. The Himalayan Mountains, which are an older type of mountain, are still 'growing' due to plate tectonics.

Valleys

A flat area of land between hills or mountains is called a valley. Valleys are usually formed by river water. The speed at which a river deepens its valley depends on the speed of the flow of the river water and the type of materials from which the river bed (the bottom of the river) is made. Softer and lighter materials are moved by water faster than hard and heavy ones. That means that a river bed made from soft sediments can be changed or deepened faster than a hard and rocky one.

Oceans

An ocean is a large body of salty water that surrounds a large land mass. After studying different rock, scientists have established that the first ocean on the Earth was formed about 4000 million years ago. Even though early Earth did not have any water, it had the chemical elements that make up a water molecule. Some scientists believe that the Earth's first rain was just cooled-down volcanic steam.

Deserts

A desert is an area that receives very little or no rain through the year. Deserts usually forms a result of climate change. Deserts have very dry air and lots of wind. Deserts can be hot or cold. During the daytime the temperature in hot deserts is very high and at night it drops to a few degrees. A cold desert is a desert that has snow in the winter. An example of a hot desert is the Sahara desert. Sometimes people call Antarctica a frozen \desert. It has not rained or snowed in some places there for over 100 years. A cold desert never becomes warm enough for plants to grow in it. Deserts cover about a fifth of the Earth's land surface.

LITHOLOGY

Lithology describes the physical characteristics of a rock unit or rock formation visible at an outcrop or core samples or with low magnification microscope. In general, the physical characteristics of a rock unit include the composition of the rock, colour, texture, and grain size.

OUTCROP

In the mountainous and sub-mountainous tracts and also in shallow plains, exposures of rocks may be easily seen forming sides of valleys or caps of hills or even uplands and slopes in level fields. An outcrop is simply defined as an exposure of a solid rock on the surface of the earth.

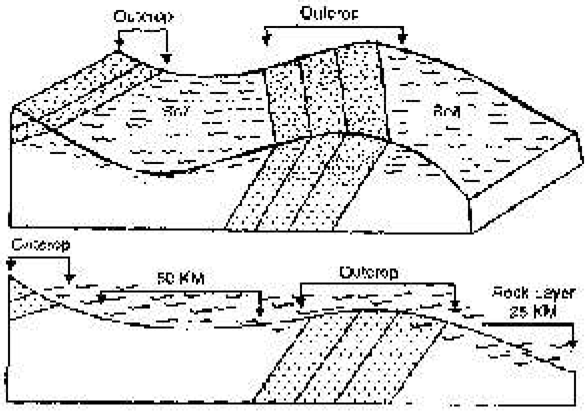


Figure 1 Denotes the Outcrop in a geological structure

Outcrop Dimensions

The **width or breadth** of the outcrop of a particular bed is given by the distance between the top and bottom edges of the bed as measured on the surface of the ground in a direction perpendicular to the strike of that particular bed. Many variations are induced in the breadth of an outcrop of a rock by the topography of the area.

The **thickness** of a particular layer or bed is the perpendicular distance between the top and bottom surface of the same layer as seen in a vertical section at right angles to the strike of the layer.

Attitude of Beds

Attitude refers to the three dimensional orientation or positioning of a given geological feature, such as a bed, a joint, a fold, etc.

Strike.

When a bedding plane (or a joint plane, or a fault plane) is cut by a horizontal plane, a line of intersection will be obtained at the surface. This direction is known as the strike, or the direction of the strike, or the line of the strike. Strike direction can obviously be represented as N 30° E or as S 30° W.

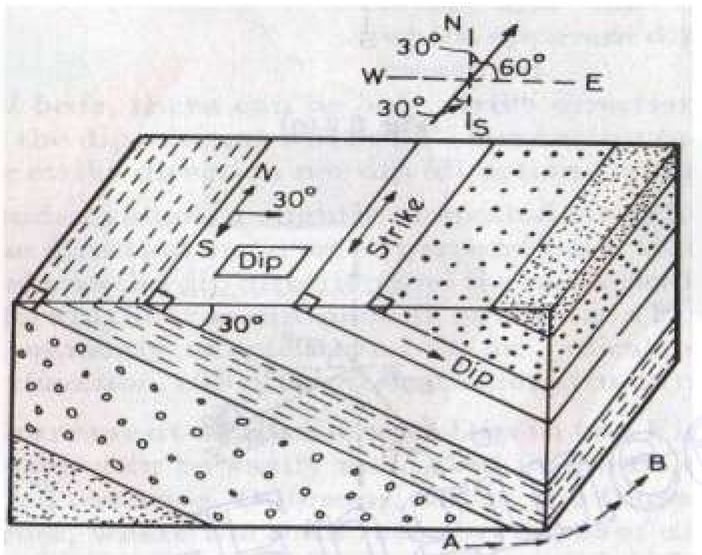


Figure 2 Represents the strike and dip of the geological formation

Dip. The dip direction is the direction along which the inclination of the bedding plane occurs. The dip amount is the angle of inclination between the bedding plane and a horizontal plane. . For example the beds are inclined at 30° to the horizontal, and their dip may be expressed as S 60° E ; when the strike direction is N 30° E or S 60° W

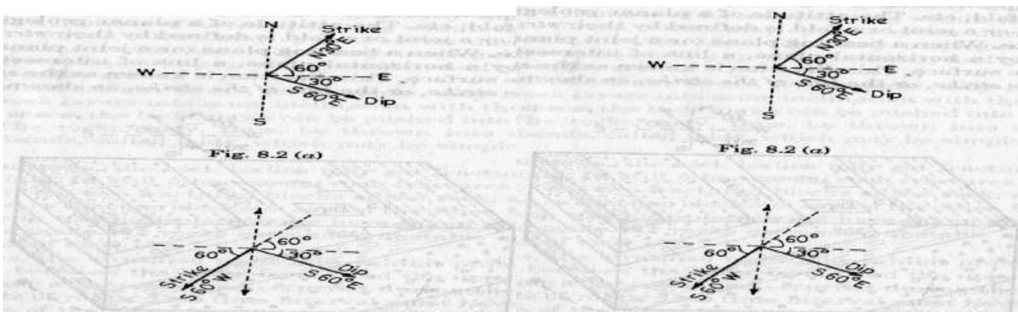


Figure 3 Representation of Strike and dip

FOLD

Folds may be defined as undulations or bends that are developed in the rocks of the Earth's crust, as a result of the stresses. These bends, called folds, may develop in any type of rock.

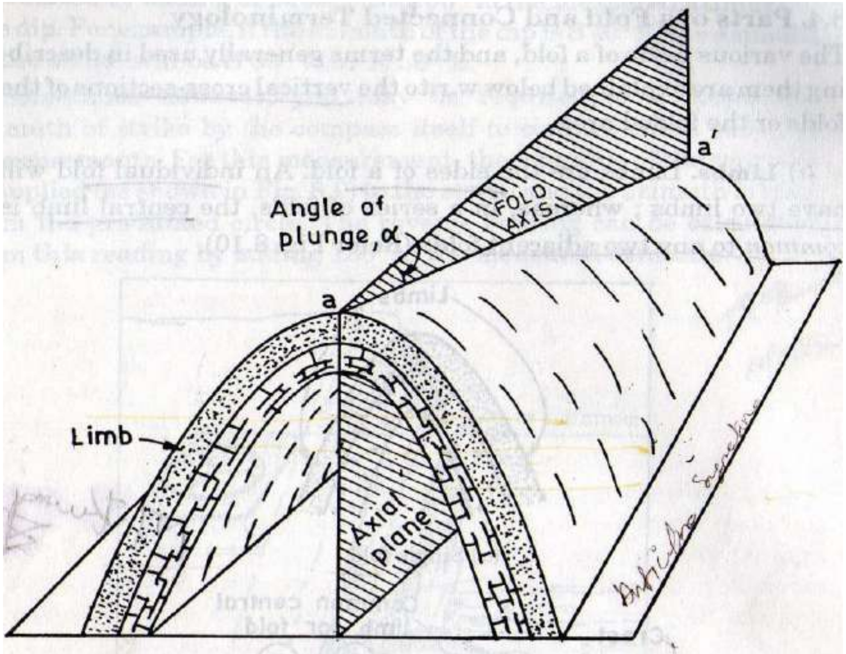


Fig. 8.11. Figure showing axial plane, fold axis, and anlge of plunge.

Figure 4 Parts of a Fold

Parts of a fold

(i) **Limbs.** Limbs are the sides of a fold. An individual fold will have two limbs;

Axial plane. Axial plane is the imaginary plane bisecting between the two limbs of a fold, thus dividing the fold into two parts, as symmetrically as possible. Axial plane may be vertical, inclined, or even horizontal.

(ii) **Axis of the Fold.** The line of intersection of the axial plane with any bed of the fold, is termed as the axis of the fold or fold axis.

(iii) **Plunge or Pitch of the Fold.** When the fold axis is inclined, the angle which it make with the horizontal, as measured in a vertical plane, is called the angle of plunge.

(iv) **Crest and Trough.** Most of the folded rocks are composed of two

general forms of folds, i.e. (i) up folded bends, and (ii) down folded bends. the line running through the highest points in an up – arched fold defines the crest; and a corresponding line running through the lowest points on the same bed, in a down – arched fold is called
the trough.

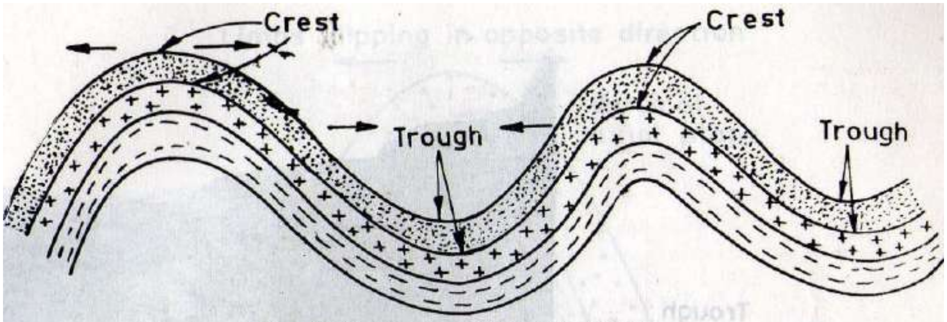


Fig. 8.12. Crest and Trough of folds.

Figure 5 Crest and Trough in folds

(v) **Anticline and Syncline.** When the beds are upfolded into an arch – like structure, it is called an anticline or an anticline fold. In such folds, the beds on either side are inclined away from the crest, and that is why the name anti – cline when the beds are down – folded into a trough like form, the structure is called a syncline in this case the beds on either side 'incline together' towards the keel.

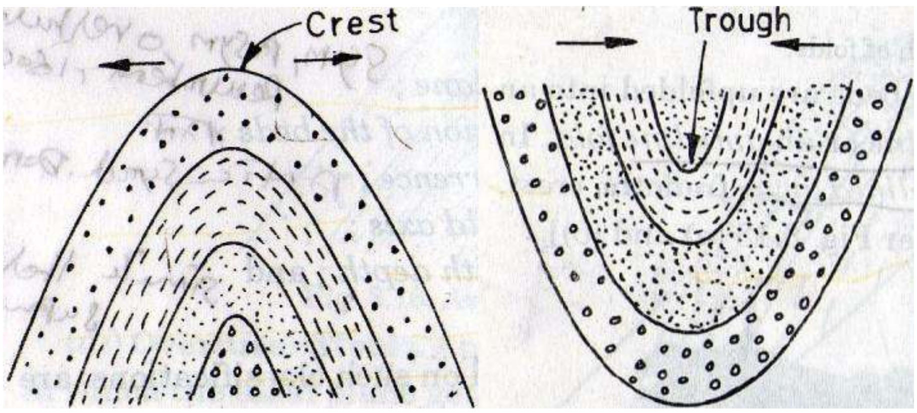


Figure 6 (a) Anticline (b) Syncline

Types of Folds and their Classification

The major classification of folds as anticlines and synclines, of which most of the folded rocks are composed of, the other classifications may be:

1. On the basis of position of axial plane
2. On the basis of degree of compression of the beds
3. On the basis of their mode of occurrence
4. On the basis of their position of fold axis
5. On the basis of their behaviour with depth and,
6. Other miscellaneous folds.

Classification of Folds on the basis of Position of Axial Plane

i. **Symmetrical folds.** A symmetrical fold is that in which the axial plane is essentially vertical the two limbs will have the same angle of dip in opposite directions.

ii. **Asymmetrical Folds.** The fold in which the axial plane is not vertical but is inclined, is called an asymmetrical fold.

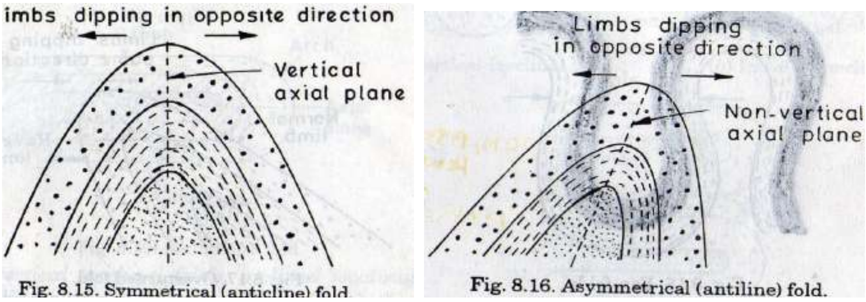


Fig. 8.15. Symmetrical (anticline) fold
Fig. 8.16. Asymmetrical (antiline) fold.

Figure 7 (a) Symmetrical folds. (b) Asymmetrical Folds

iii. **Overturned folds.** An overturned fold is a severely folded fold, in which the axial plane gets so much inclined that the two limbs of the fold dip in the same general direction.

iv. **Recumbent Folds.** These are extreme types of overturned folds, in which the axial plane acquires an almost horizontal position.

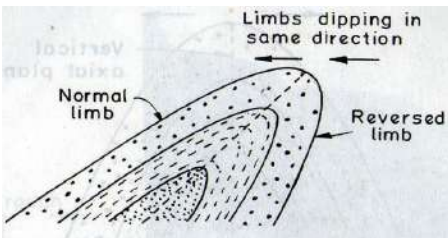


Fig. 8.17. Overturned fold.

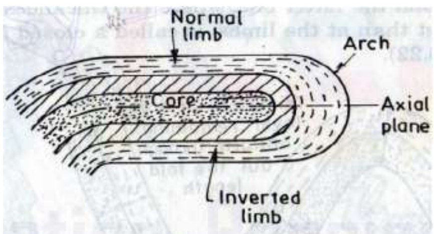


Fig. 8.19. Recumbent fold.

Figure 8 (a) Overturned folds (b) Recumbent Folds

v. **Isoclinal Folds.** Isoclinals folds are those in which the limbs are dipping essentially in the same direction and at equal angles, so that their axial planes are essentially parallel folds may be vertical, inclined, or even horizontal.

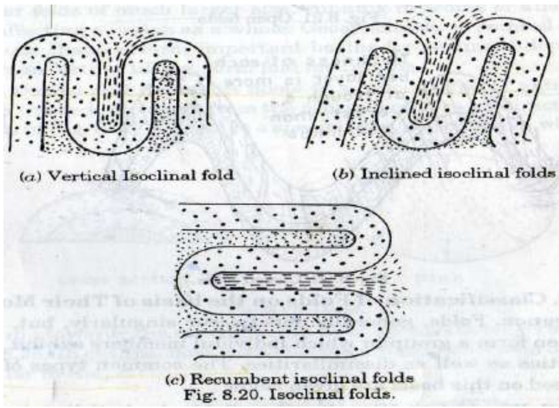


Figure 9 Isoclinal Folds

Classification of Folds on the basis of Degree of Compression of the Beds

In the case of severe compression, the beds may get thinner at the limbs and thicker at the crests and troughs. The former type of folds, where the thickness of bed is the same throughout its fold layer, is called an open fold; and the latter one, where the thickness is more at trough and crest than at the limbs, is called a closed fold.

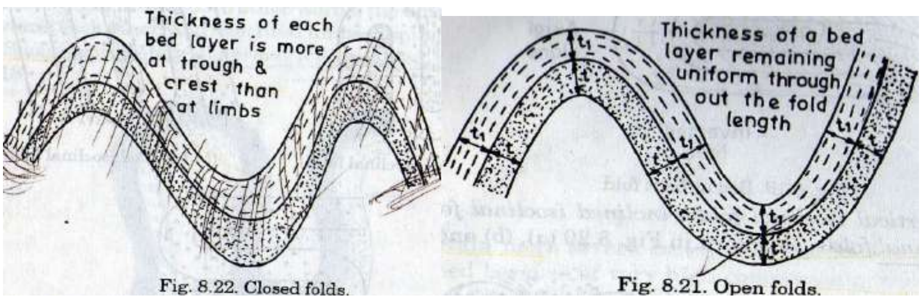


Figure 10 (a) closed folds (b) open folds

Classification of Folds on the basis of their mode of Occurrence

Anticlinorium and Synclinorium Folds. An Anticlinorium fold is a large anticline which is further thrown into smaller folds. A Synclinorium fold is a large syncline which is further thrown into smaller folds.

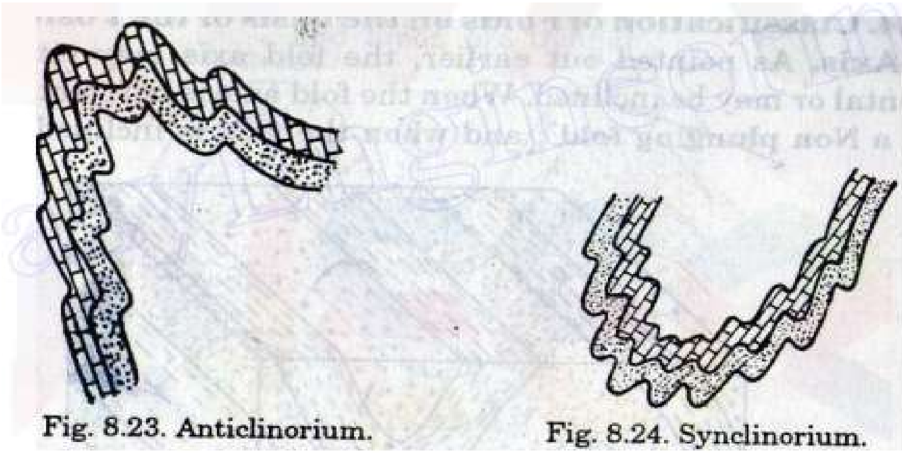


Figure 11(a) Anticlinorium, (b) Synclinorium Folds

Domes and Basins. A dome is a special type of anticline in which the beds dip away from the central point, in all directions a basin is a special type of syncline in which the beds dip towards the central point.

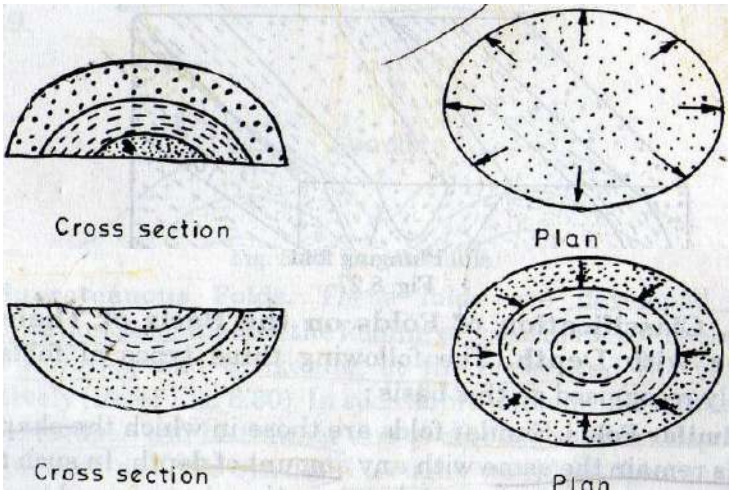


Figure 12 (a) Dome, (b) Basin

Classification of Folds on the basis of the Position of Fold Axis

The fold axis may either be horizontal or may be inclined. When the fold axis is horizontal, it is called a Non plunging fold; and when the axis is inclined to the horizontal, it is called a plunging fold. The angle of inclination being called as the angle of plunge.

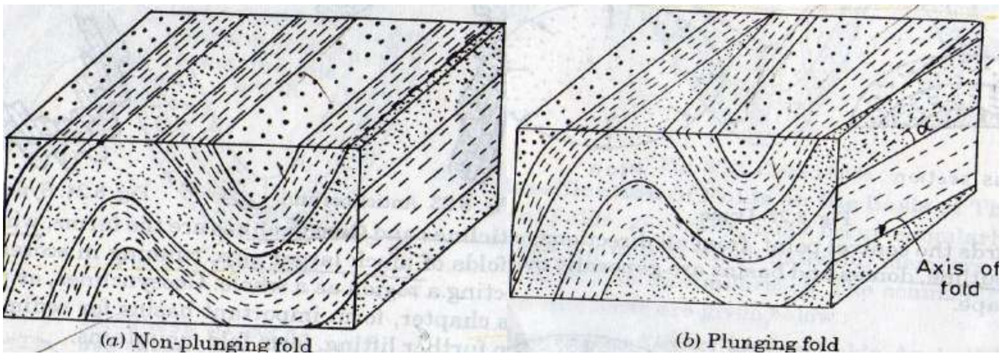


Figure 13 (a) Non-Plunging Fold, (b) Plunging fold

Classification of Folds on the Basis of their Behaviour with Depth

Similar Folds. The thickening at axial regions (i.e. at crests and troughs) and thinning of the limbs, hence known as zone of rock flowage

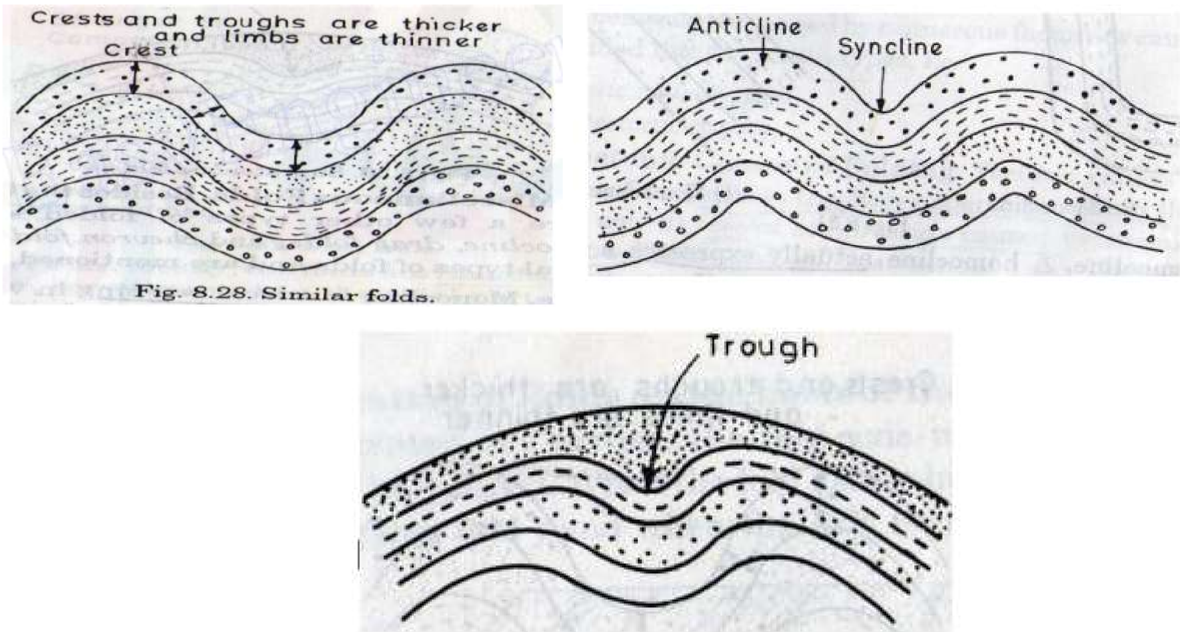


Figure 14(a) Similar Folds, (b) Parallel Folds, (c) Supratenuous Folds

Parallel Folds. Parallel folds are those in which the shape of the folds varies with depth, but the thickness of the folded bed layers remains more or less the same. In such folds, the anticlines become sharp and sharper with depth; whereas, the synclines become broad and broader with depth.

Supratenuous Folds. These folds exhibit thinning and thickening at the crests and the troughs.

Other Miscellaneous Folds

Monocline. Monocline is a local warping in which the otherwise horizontal strata, exhibit an abruptly steep inclination. This inclination of a monocline may sometimes become enormous (i.e. almost vertical from horizontal) so that a large difference of elevation between the strata on either side of the bend is introduced.

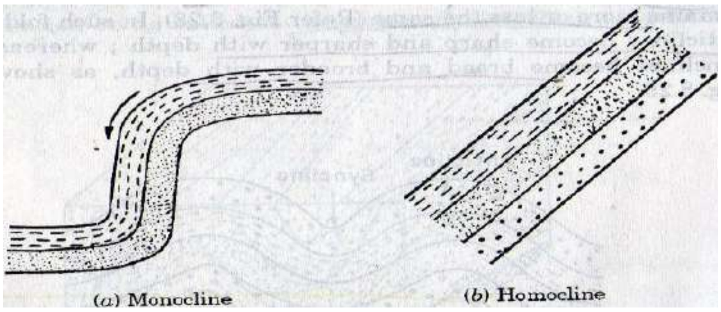


Figure 14(a) Monocline, (b) Homocline

Homocline. A homocline actually expresses a sequence of strata dipping in the same direction, at a uniform angle.

Drag Folds. Drag folds are the minor folds developed within the body of a weaker bed enclosed between two stronger beds. Such folds are developed due to the dragging effects. The weaker bed is called the incompetent bed, and the stronger beds are called the competent beds.

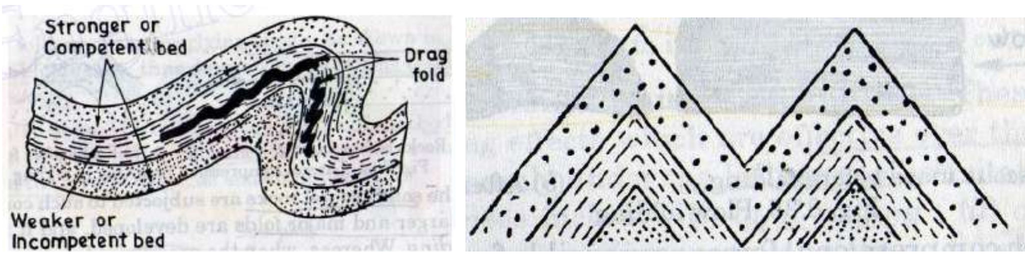


Figure 15 (a) Drag Folds, (b) Chevron Folds

Chevron Folds. Mostly, the folds are rounded along their axial parts. However, sometimes when the axial parts are not rounded and remain pointed, and then they are called Chevron folds.

Causes of Folding

1. **Tectonic causes**

Tectonic are those which are produced due to the forces operating within the Earth's crust, such as: (i) lateral compression caused by shrinkage; (ii) igneous instructions; and salt instructions.

Lateral Compression. The stresses are developed within the Earth's crust due to shrinkage, resulting from the differential cooling of the initial hot molten Earth.

Igneous Intrusions, Intrusions of magma from beneath may result in the folding of the overlying strata. The anticlinal folds may, thus develop easily during the formation of laccoliths.

Salt Intrusions. The upward movements of salt bodies under pressure (i.e. intrusions) from beneath may also result in the arching up of the strata.

2. **Non – tectonic causes**

Non – Tectonic Causes of Folding. These include all those rock-folding effects which are effective over the ground surface, resulting mainly under the influence of gravitational force. A few of these causes include: (i) land sliding; (ii) creeping; (iii) differential compaction; (iv) isostatic setting; (v) subsidence into solution cavities; and (vi) glaciation.

(i)Landsliding, Landsliding may sometimes produce folding, when large parts of rock beds slide down the slopes and get buckled up o folded because of Compression produced during their coming to rest.

Creeping. The slow movement or creeping along hill slopes may result in the bending of the weak beds.

Differential compaction. During the formation of sedimentary rocks, if the underlying substratum is of an undulating relief, the deposited sediments may also acquire similar undulations (folding) on compaction

Isostatic Setting. Due to the gradual accumulation of the sediments in wide basins of deposition, the lower rock layers may get bent due to the ever increasing load from above, thus producing folding.

Subsidence into solution cavities. Solution of some part of an underlying formation may result in the subsidence of the overlying beds, thus producing folding effects in these upper layers.

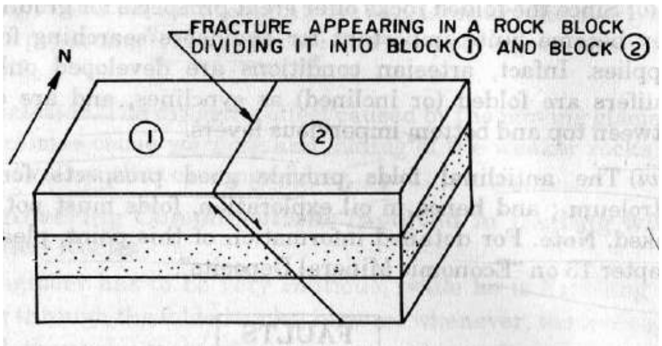
Glaciations. The dragging effect caused by the moving glaciers may sometimes cause warping and folding of the weaker rocks in the glacial valley, thus causing folding.

Engineering Considerations involved in Dealing with Folded Rocks

A civil engineer has to be very cautious, while he is handling or excavating through the folded rocks, because whenever, the folds are disturbed, they release the stored energy and may damage the site in various ways. Moreover, folded rocks are generally highly fractured, particularly along the axial parts. These fractures, not only make the rocks weak, but also act as channel-ways for the surface waters to percolate. (i) Synclinal folded rocks may yield hard and tough quality stones; whereas, anticlinal folded rocks will yield weaker stones. (ii) Fractured folded rocks are highly permeable, and as such may pose numerous problems in dam construction in such areas; heavy leakage from beneath the dam occur. (iii) The anticlinal folds provide good prospects for stored petroleum.

FAULTS

Due to the stresses developed within the Earth's crust, the rock formation of the Earth may either get folded or fractured. Folding is generally favoured by the development of compressional stresses within the crust; whereas, fracturing is favoured by the shearing stresses. A rock fracture or a fracture surface along which relative movement due to internal shearing stresses between the fractured parts occurs, is called a fault. The phenomenon of development of such fractures and occurrence of the relative displacement of blocks is known as faulting.



(a) Conditions before faulting. Only a rupture, shown, developed in a block of the crust.

(b) Conditions after faulting. Displacement occurring along the fracture surface.

Fig. 8.43. Development of a fault.

Figure 16 General representation of faults

Fault Terminology

Fault Plane. The surface along which fracture occurs in the rock body; and there occurs a relative movement between the so formed rock-parts, is termed as fault plane or fault surface.

Fault trace or Fault outcrop or Fault line. This may be defined as the line of intersection of a fault plane with the ground surface.

Dip and Strike of the fault. The inclination of the fault plane, with the horizontal is called the 'dip of the fault'. The direction perpendicular to the dip direction is nothing but the 'strike of the fault.

Hade. Hade is the angle which the fault plane makes with the vertical.

Hanging wall and Footwall. A fault plane separates the two blocks, and each

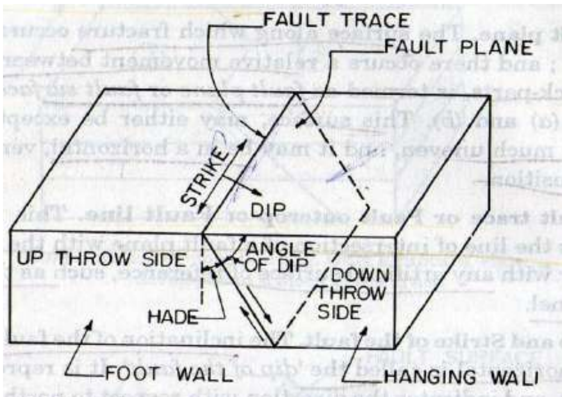
block is known as a wall. Now, if the fault plane is inclined, then the block lying over the fault plane (though it may or may not be lying at a higher elevation than the other block) is called the handing wall; whereas, the block lying beneath, i.e. underside of the fault plane is called the foot wall.

Upthrow side and down-throw side. Of the two blocks of a fault, the one which moves up with respect to the other is called the upthrow side; and the one, which moves down with respect to the other is called the down-throw side.

Throw. The total vertical displacement in a fault is known as the throw of the fault.

Heave. The total horizontal displacement in a fault is known as heave.

Slip and its types. Slip of a fault is defined as the relative displacement of two points which were initially against each other.



(*b*) **Block diagram without showing the actual movement between the blocks**

Figure 17 Block Diagram for Fault terminology

The maximum displacement is known as Net slip: displacement along the strike of the fault plane is known as Strike slip; and the displacement along the dip of the fault plane is known as Dip slip.

Slicken Sides. The moving blocks in a faulting, may cause a lot of scratching

on one another along the fault plane. Due to this scratching, sometimes, striations or grooves may be produced. Such striated or grooved surfaces produced by faulting are called slicken sides.

Types of Faults and their Classifications

1) on the basis of the apparent movement of the fault blocks
2) on the basis of the amount of the dip of the fault
3) on the basis of the attitude of the fault
4) on the basis of the direction of the net slip

5) on the basis of their general pattern or mode of occurrence

Classification of Faults on the basis of the Apparent Movement of the Fault Blocks

Normal fault. A normal fault is the one in which the hanging wall has apparently moved down with respect to the foot-wall. The fault planes of majority of normal faults dip more than 45^o (i.e. angle of hade > 45^o)

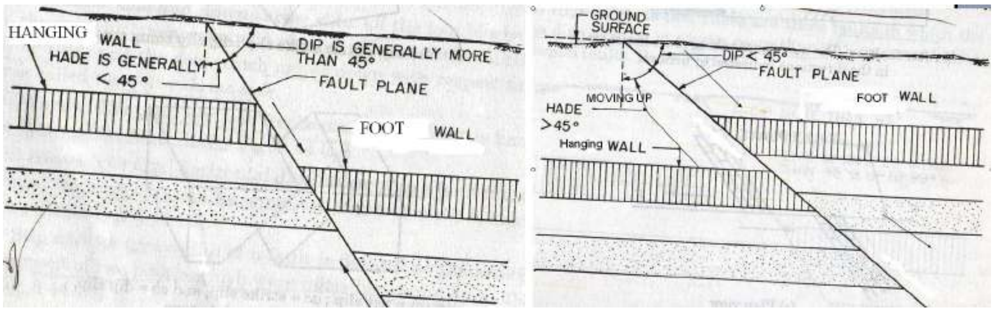


Figure 18 (a) Normal Fault (b) Thrust fault

Thrust fault. A thrust fault or a thrust is one in which the hanging wall has apparently moved up with respect to the foot wall.

Transcurrent fault or **Tear fault** or **Transverse fault**. It is that fault in which the blocks have moved against each other in an essentially horizontal direction.

Vertical fault. That fault in which the fault plane is vertical, and the resulting

movement of blocks is also in vertical direction, is termed as vertical fault.

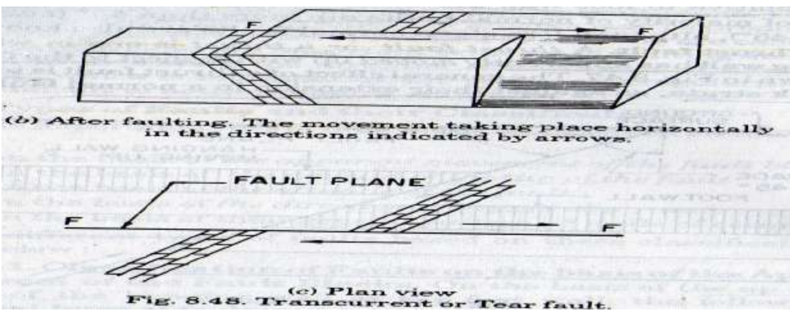
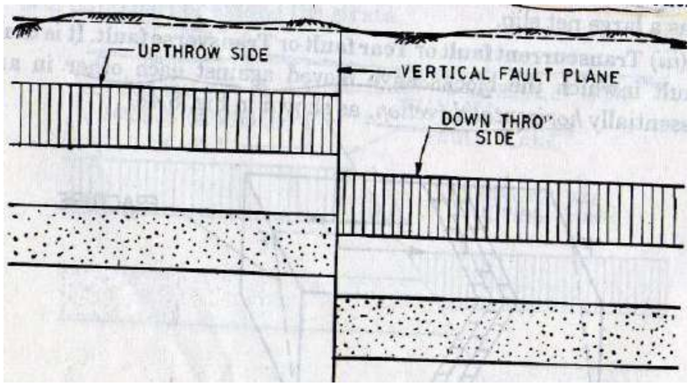


Figure 19(a) transcurrent fault



Classification of faults based on the Amount of the Dip of the Fault

High angle faults. These are those faults in which the fault plane dips steeply, at angles more than 45°.

Low angle faults. These are those faults in which the fault plane dips gently at

angles less than 45°

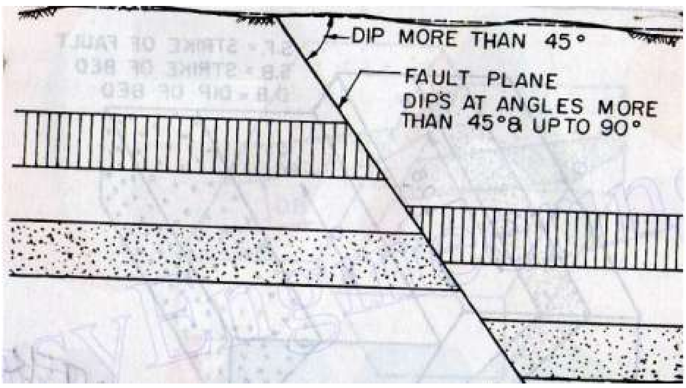
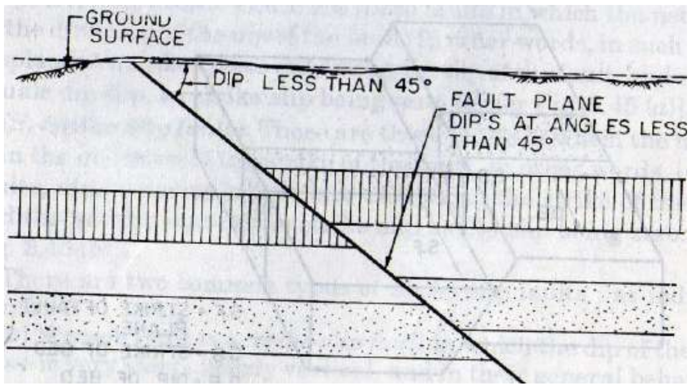


Figure 20(a) High angle Fault

Figure 20(b) Low angle Fault



Classification of Faults on the basis of the Attitude of the Fault

Strike fault. A strike fault is that in which the strike direction of the fault plane is essentially parallel to the strike direction of the adjacent beds.

Dip fault. In dip fault the strike of the fault plane is essentially normal (perpendicular) to the strike of the adjacent beds.

Oblique fault. An oblique or diagonal fault is that in which the fault plane strikes the beds neither parallel nor normally, but strikes obliquely or diagonally

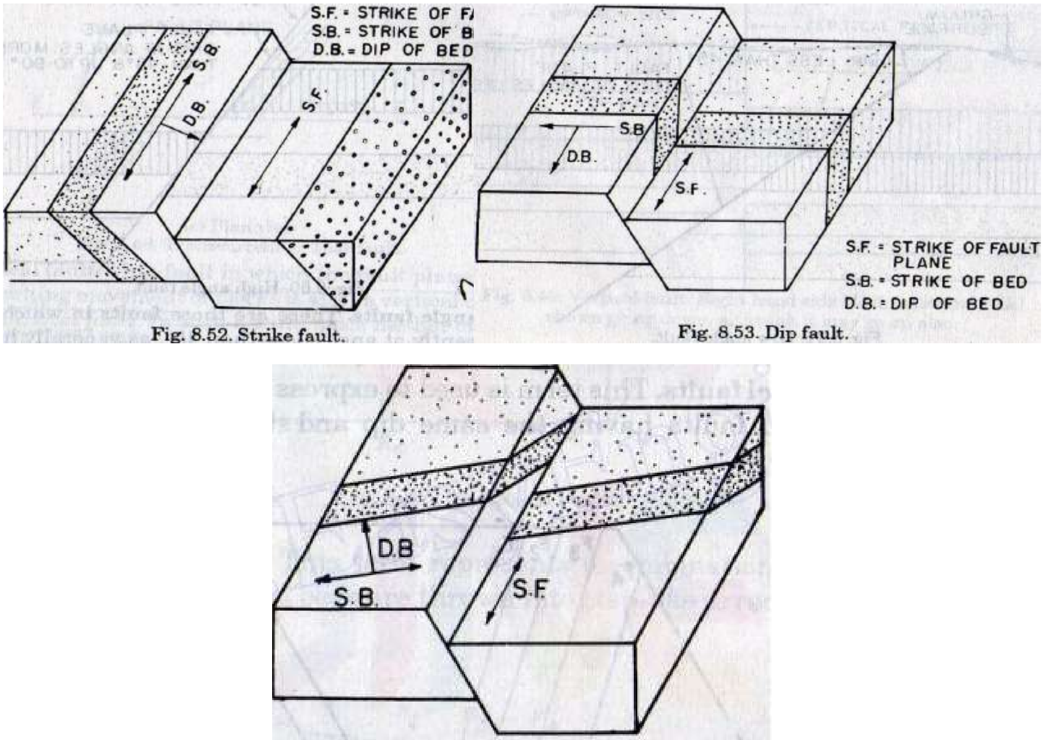


Figure 21 (a) Strike fault (b) Dip fault (c) Oblique fault

Classification of Faults based on the direction of the Net Slip of the Fault.

Dip Slip faults. These are those faults in which the net slip is in the direction of the dip of the fault.

Strike Slip faults. These are those faults in which the net slip is in the direction of the strike of the fault.

Classification of faults on the basis of their General Pattern or Mode

of Occurrence

Parallel faults. This term is used to express the occurrence of a number of fault having the same dip and strike.

Radial faults. These comprise a group of faults that are arranged in a radial manner. Thee faults appear to be radiating from a common point.

Enechelon faults. This term is used to express a group of faults that overlap one another.

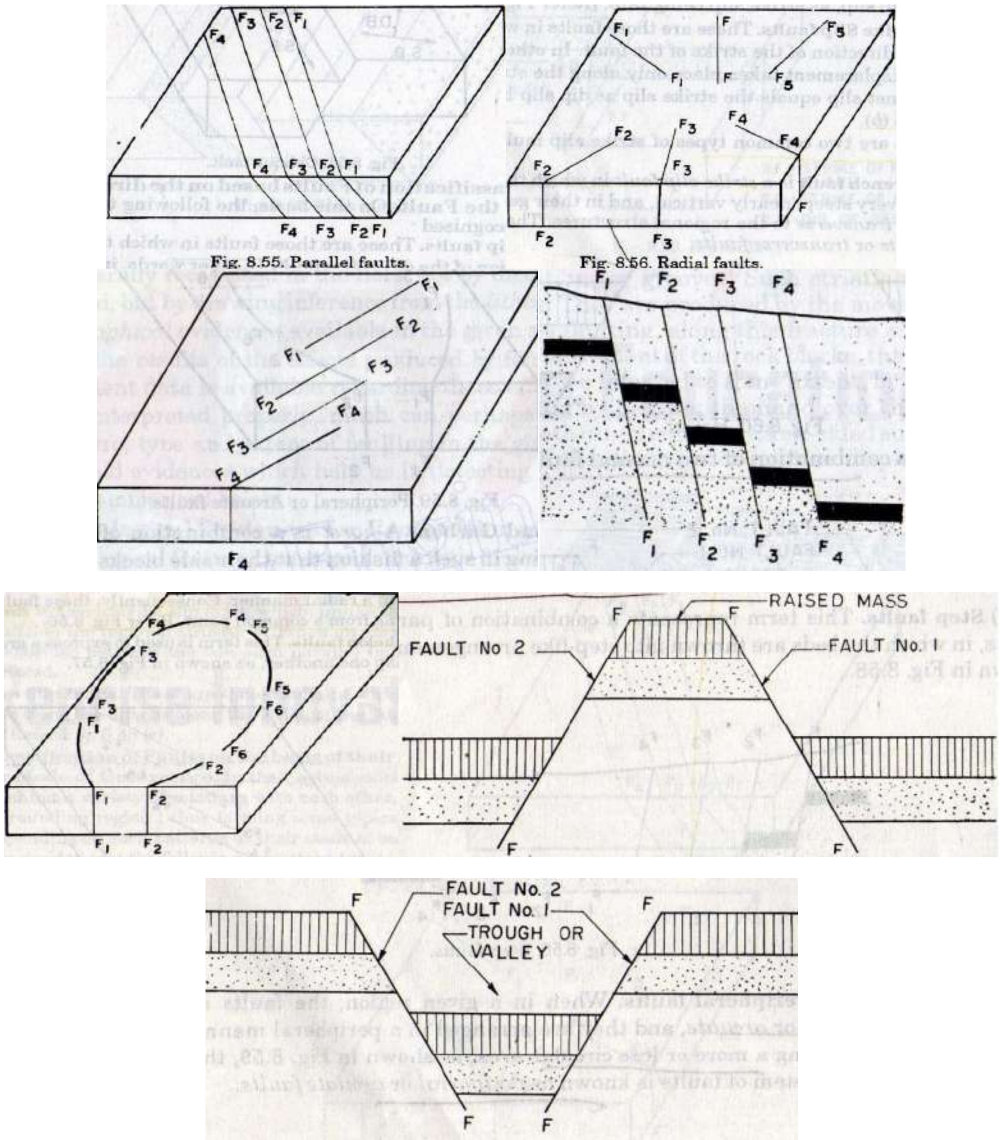


Figure 22 (a) Parallel faults (b) Radial faults (c) Enechelon faults (d) Step faults (e) Peripheral faults (f) Horst (g) Garben

Step faults. This term represents a combination of parallel faults, in which the beds are thrown into step-like arrangements.

Peripheral faults. When in a given region, the faults are curved or arcuate, and they are arranged in a peripheral manner, enclosing a more or less circular area.

Horst and Garben. A horst is a combination of two normal faults, occurring in such a fashion that their side blocks have moved down with respect to the central block, resulting in the formation of a raised land mass. A **garben** is also a combination of two normal faults.

Causes of Faulting

Faults are essentially the shear or sliding failures, resulting from tensional, compressional, or rotational stresses acting on the crustal rock masses. Normal faults of gravity faults are assumed to have been formed under the influence of horizontal tension, whereby the crust would rupture or fail along vertical or nearly vertical fractures. Such faults are, therefore, sometimes called as tension faults. Thrust faults may be assumed to be originating from compressive stresses, which may throw the rocks into folds, and these intensely folded rocks getting fractured and faulted under shear, at a later date. These reverse faults are therefore, sometimes called compressional faults.

Engineering Considerations Involved in Dealing with the Faulted Rocks

Faulted rocks generally offer unstable sites from engineering considerations, because there has been displacements along the fault(s) in the past and further fresh movements may take place at any time in future. An engineer, as a general rule, try to avoid locating any of his major structures on fault or rather even in its vicinity.

JOINTS

Joints may be defined as cracks or fractures present in the body of a rock, along which there has been no relative movements as happen in the case of faults. These joints or cracks may be of small sizes extending only for a few centimetres in length, or may be extremely extensive.

Open joints are those in which the blocks are separated or 'opened out' for some small widths in a direction at right angles to the fracture surface. In **Close joints**, however, there is no such separation. A rock is generally traversed profusely by various joints, but some of them may be more prominent and well developed, extending continuously for considerable lengths, as compared to others. Such prominent joints are called master joints or major joints.

In the case of beds or faults, the inclination of a joint plane with the horizontal is called the **dip of the joint.** It is expressed as the angle in degrees, and the direction with respect of north, south, east and west. The line along which the joint plane meets the surface is called the **strike of the joint**, the strike direction being perpendicular to the dip direction.

Classifications and Types of Joints

1) geometrical classification ;
2) genetic classification

The Geometrical Classification of Joints. The geometrical classification of joints is based on the attitude of the joints with respect to that of the beds. Three types of joints, i.e. strike joints, dip joints and oblique joints.

Strike joints are those in which the strike of the joints is parallel to the strike of the beds.

Dip joints are those in which the strike of the joints is perpendicular to the strike of the beds (i.e. parallel to the dip o the beds), and (iii) Oblique joints are those in which the strike of the joints in neither parallel nor normal to the strike of the beds.

The Genetic Classification of Joints. Depending upon the cause of their origin, joints may be divided into (i) Tension joints and (ii) Shear joints.

Tension joints. Tension joints are those which are formed due to tensile forces or stresses produced in the rocks, either during their formation or after their formation. The important types of tension joints are :(a) columnar joints ; (b) mud cracks ; (c) sheeting joints ; and (d) mural joints

Columnar joints. Developed in igneous volcanic rocks, particularly Basalts. These joints are hexagonal in plan, and are produced in the body of the cooling magma, due to the contraction caused by cooling.

Mud cracks are also tension joints, formed in a similar manner are columnar
joints; but here, the contraction occurs due to the drying of the mud.

Sheet joints. The horizontal joints developed in massive igneous rocks, especially Granites. These horizontal joints are closely spaced in the upper layers, and become progressively farther apart with depth.

Mural joints. These are three sets of joints, mutually perpendicular (two sets of vertical joints and one set of horizontal joints) to one another, developed generally in igneous rocks, such as Granites. The spacing between the joints is more or less equal, so that the rock is split into cubical blocks, or murals

Shear Joints. Shear joints are formed by the shearing stresses, which tend to slide (or actually slide) one part of the rock against the other.

Joints in Different Rocks

The joints are developed in three different types of rocks

Joints in Igneous Rocks. Igneous rocks are joined to varying degrees, depending upon the conditions under which the magma has cooled down for their formations. Tension Joints are generally developed in igneous rocks due to contraction off magma. Columnar tension joints are commonly developed in volcanic igneous rocks like Basalts; whereas, Mural tension joints are developed in massive deep seated igneous rocks like Granites. Sheeting tension joints are also sometimes developed in Granites, which make this rock look like a bedded sedimentary formation.

Joints in Sedimentary Rocks. Generally, two sets of joints, more or less perpendicular to each other, and also to the bedding of the rock, are developed in sedimentary rocks. In folded sedimentary rocks, tension joints are developed near the axial parts, and shear joints are developed in the body of the folds (i.e. limbs). Fine-grained sedimentary rocks like clays may develop mud cracks.

Joints in Metamorphic Rocks. These rocks are also sometimes heavily jointed, although regularly exhibited jointing patterns are rather poor.

Engineering Considerations Involved in Dealing with Jointed Rocks

For construction of any major civil engineering structure in any area, it is absolutely necessary to investigate the rock joints thoroughly, mainly because joints act as sources of weakness for the rocks, and also as sources of leakage through the rocks. Hence, if the proposed foundation rocks for a dam or a reservoir happens to be heavily jointed, and if the water-table of the region is low, then the leakage from the reservoir to the underground may be very heavy, finally resulting in abandoning the proposed site, and to choose better one. The Joints in rocks play a very important role in landslides in hilly regions, because they serve as slip surfaces.

LAND SUBSIDENCE

Land subsidence is the gradual settling or sudden sinking of land from subsurface movement of materials. Subsidence is one of the most diverse forms of ground failure, ranging from small or local collapses to broad regional lowering of the earth's surface. Land subsidence occurs when large amounts of groundwater have been withdrawn from certain types of rocks, such as fine-grained sediments. The rock compacts because the water is partly responsible for holding the ground up. When the water is withdrawn, the rocks falls in on itself. You may not notice land subsidence too much because it can occur over large areas rather than in a small spot.

The causes of subsidence are as diverse as the forms of failure, and include drainage of organic soils, underground mining, thawing permafrost, dissolution in limestone aquifers, first-time wetting of moisture-deficient low-density soils, natural compaction, liquefaction, crustal deformation, subterranean mining, and withdrawal of fluids.

Classification and field identification of folds, faults using Satellite images.

The Satellite images as shown in Figure 23 exhibit outcrops of doubly plunging anticlines and synclines having different pattern, shape, size and arrangement. Generally, anticlines form linear higher ridges with well-defined geometry exhibiting the effect of deformational processes that the region has experienced. The top layers of the anticlinal folds have been removed due to erosional processes of natural agents exposing fold limbs and plunging noses which are identifiable on satellite images. Fold limbs belonging to either anticline or syncline are recognized based on the nature of erosional surfaces, geometrical arrangement, the nature of exposed elongated beds and the bedding arrangement pattern as displayed on satellite images.

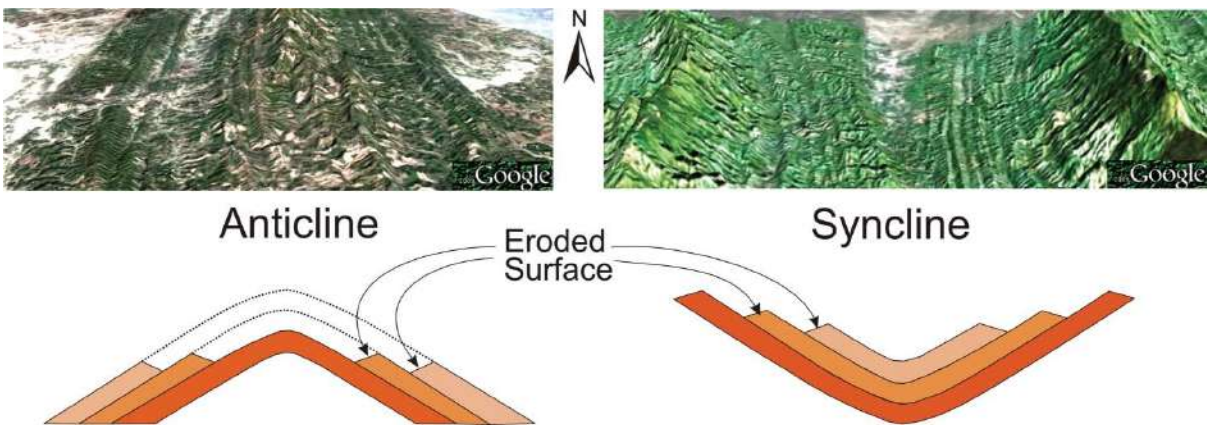


Figure 23 Satellite images and identification of folds

The Kutch Mainland Fault (KMF) is depicted in Figure 24. The line segments represented in the image gives the fault zones in the particular area. Comparison of two types of fault system is given in the Figure 24, (a) In this the disconnected fault system is linked by relay structures along with the fault in the northernmost part of a basin in India and also mature/advance fault system segmented by transverse faults. Both of these faults have reverse dip-slip faults developed as a result of compressional forces related to Himalayan Disconnected fault systems. Early stage faults can form matured faults by the effect of underneath pre-existing basement structures.

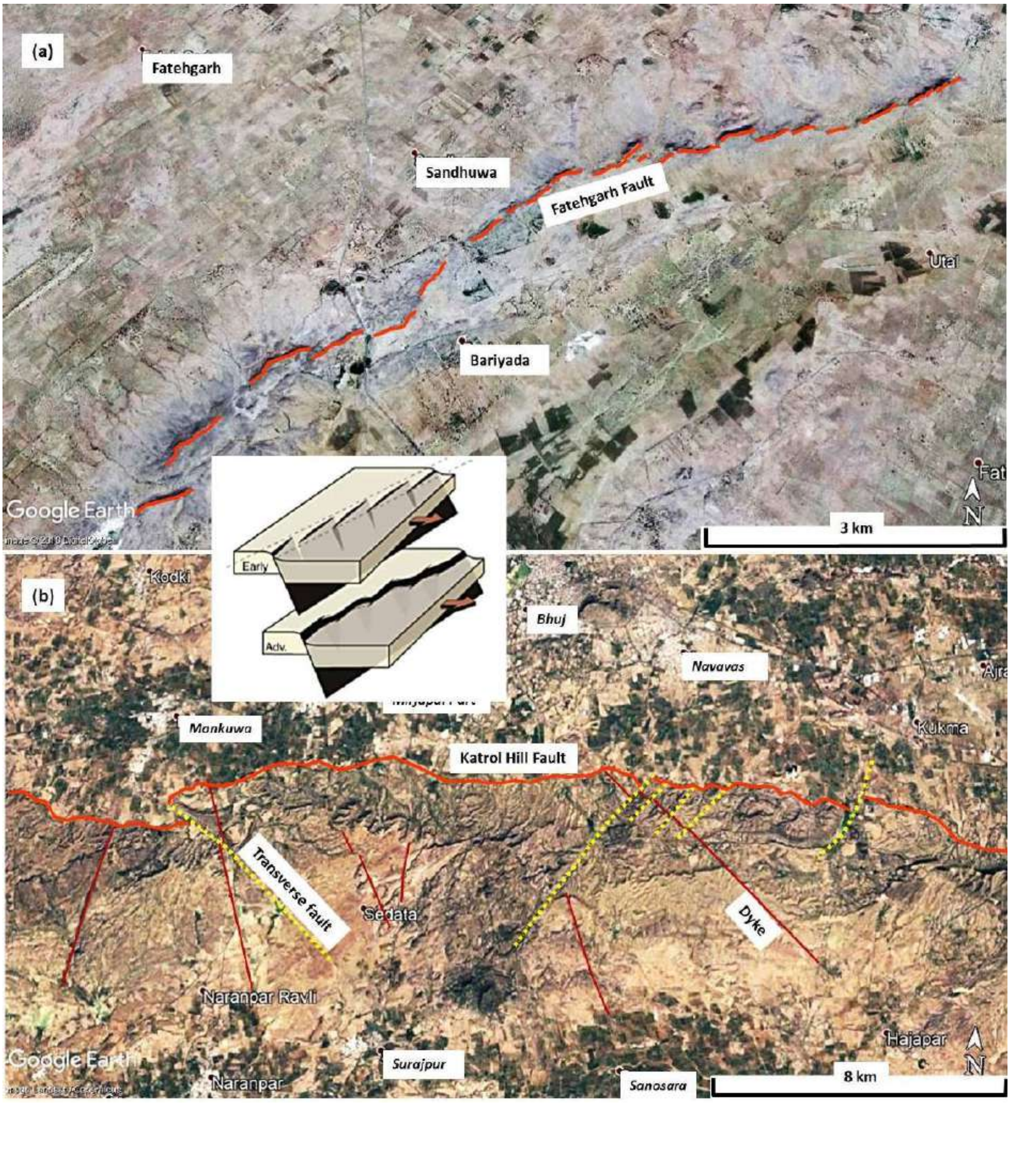


Figure 24 Satellite images and identification of faults

UNIT –III

Syllabus:

Geographic Information System (GIS) Introduction, key components, map projections, data entry & preparation – Spatial data input, Raster Data Model, Vector Data Model, Raster Vs Vector. Basic Overlay operations.

Learning Material

Introduction

IS stands for Geographical Information System. It is defined as an integrated tool, capable of mapping, analyzing, manipulating and storing geographical data in order to provide solutions to real world problems and help in planning for the future. GIS deals with what and where components of occurrences. For example, to regulate rapid transportation, government decides to build fly-over (what component) in those areas of the city where traffic jams are common (where component).

GIS means differently to different people and therefore has different definitions. For example, Burrough (1998) defined GIS as “ a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes”

Definitions

GIS is defined as an information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data or geospatial data, in order to support decision making for planning and management of land use, natural resources, environment, transportation, urban facilities, health services so on.

MAP a diagrammatic representation of an area of land or sea showing physical features, cities, roads, etc. A map is a two dimensional representation of earth surface which uses graphics to convey geographical information. It describes the geographical location of features and the relationship between them. Maps are fundamental to society. Cartography refers to the art and science of map preparation. Though, the earliest of the maps were technically not as impressive as they are today but they certainly highlighted their role in communicating information about the location and spatial characteristics of the natural world and of society and culture. The new discoveries in Science and Geography fortified maps with facts and technical details. Improvements in the fields of Geodesy, Surveying and Cartography helped in bringing the maps to their present form. The digital technology has altered the way of creating, presenting and distributing the geographic information. The conventional cartography is now getting replaced by computer aided designs and graphics, and the analog maps (paper maps) by digital maps. The growing field of technology promises to bring more advances to Cartography to render maps and allied services that serve the society in a better manner.

Map Scale

The size of earth is too big to be represented as it is on a map. To represent the whole earth or part thereof on a small map, the concept of scale is used. The proportion chosen for a map is its scale. It is the relationship between distance on map and distance on ground that tells what distance on map corresponds to what distance on ground.

Representation of scale

There are three ways in which a scale can be depicted on a map:
Expressed in words such as '2 centimeters to the kilometer' which means two centimeters on the map represents one kilometer on the ground. Though it is the simplest way of expressing a scale but it has the following drawbacks associated with it:

1. Statement

The fractional distances involve mathematical calculations
Different countries have different units of length, expressing a statement scale on a map may not be understood by the foreigners.

Map with scale in Statement

2. Representative fraction

It is expressed in fraction. If the scale is 1:50000, it means that 1 unit of measurement on map represents 50,000 units on ground. It is also known as numerical scale.

$$R.F = \frac{Distance\ between\ two\ points\ on\ the\ map}{Distance\ between\ the\ same\ two\ points\ on\ the\ ground}$$

The distance on map and the distance on the ground must be in the same units of length. The advantage of this scale is that- it can be read into different units of length. For example the map with a scale 1:50,000 would mean that a distance of 1 cm on ground represents 50,000 cm on the ground or it can also be said that a distance of 1 feet on ground represents 50,000 feet on ground.

Map with scale in Representative Fraction

3. Graphic: The scale is shown in form of a strip, where the strip is divided into a number of equal parts and is marked to show what these divisions represent on actual ground. It is also known as plain scale or linear scale.

For example, the above scale represents that 1 division of a strip on map represents 10 km on ground.
The advantage of a graphic scale is that it is reduced or enlarged in the same proportion in which the map is reduced or enlarged.

Types of Maps

The maps can be classified on the following criteria:

1. Scale
2. Purpose

Scale is important for correct representation of geographical features and phenomenon. Different features require different scales for their display. For example preparation of a cadastral map of a village and the soil map of a state would use different scale for representing the information. According to scale, maps can be classified as follows:

a. Cadastral : These maps register the ownership of land property. They are prepared by government to realize tax and revenue. A village map is an example of cadastral map which is drawn on a scale of 16 inches to the mile or 32 inches to the mile.

b. Topographical: Topographical maps are prepared on fairly large scale and are based on precise survey. They don't reveal land parcels but show topographic forms such as relief, drainage, forest, village, towns etc. The scale of these maps varied conventionally from 1/4 inch to the mile to one inch to the mile. The topographical maps of different countries have varying scales.

Topographical survey map of British Ordnance Survey are one inch maps.
The scale of European toposheets varies from 1:25000 to 1:100000.
USA toposheets are drawn on the scale 1:62500 and 1:125000.
The international map which is a uniform map of the world is produced on the scale of 1:1000000.

c. Chorographical/Atlas: Drawn on a very small scale, atlas maps give a generalized view of physical, climatic and economic conditions of different regions of the world. The scale of atlas map is generally greater than 1:1000, 000.

On the basis of **Purpose** or the content, the maps can be classified as follows:
a. Natural Maps:
These maps represent natural features and the processes associated with them. Given below is the list of some such maps:

Astronomical map : It refers to the cartographic representation of the heavenly bodies such as galaxies, stars, planets, moon etc.

Geological map : A map that represents the distribution of different type of rocks and surficial deposits on the Earth.

Relief map : A map that depicts the terrain and indicates the bulges and the depressions present on the surface.

Climate map : A climate map is a depiction of prevailing weather patterns in a given area. These maps can show daily weather conditions, average monthly or seasonal weather conditions of an area.

Vegetation map : It shows the natural flora of an area.

Soil map : A soil map describes the soil cover present in an area.

b.Cultural Maps
These maps tell about the cultural patterns designed over the surface of the earth. They describe the activities of man and related processes. Given below is the list of such maps:

Political map: A map that shows the boundaries of states, boundaries between different political units of the world or of a particular country which mark the areas of respective political jurisdiction

Military map : A military map contains information about routes, points, security and battle plans.

Historical map : A map having historical events symbolized on it.

Social map : A map giving information about the tribes, languages and religions of an area.

Land-utilization map : A map describing the land and the ongoing activities on it.

Communication map : A map showing means of communication such as railways, road, airways etc.

Population map : A map showing distribution of human beings over an area.

Coordinate System

A coordinate system is a reference system used for locating objects in a two or three dimensional space

Geographic Coordinate System

A geographic coordinate system, also known as global or spherical coordinate system is a reference system that uses a three-dimensional spherical surface to determine locations on the earth. Any location on earth can be referenced by a point with longitude and latitude.

We must familiarize ourselves with the geographic terms with respect to the Earth coordinate system in order to use the GIS technologies effectively.
Pole: The geographic pole of earth is defined as either of the two points where the axis of rotation of the earth meets its surface. The North Pole lies 90° north of the equator and the South Pole lies 90° south of the equator.

Latitude : Imaginary lines that run horizontally around the globe and are measured from 90° north to 90° south. Also known as parallels, latitudes are equidistant from each other.

Equator : An imaginary line on the earth with zero degree latitude, divides the earth into two halves–Northern and Southern Hemisphere. This parallel has the widest circumference.

Longitude : Imaginary lines that run vertically around the globe. Also known as meridians, longitudes are measured from 180° east to 180° west. Longitudes meet at the poles and are widest apart at the equator

Prime meridian : Zero degree longitude which divides the earth into two halves–Eastern and Western hemisphere. As it runs through the Royal Greenwich Observatory in Greenwich, England it is also known as Greenwich meridian

Equator (0°) is the reference for the measurement of latitude. Latitude is measured north or south of the equator. For measurement of longitude, prime meridian (0°) is used as a reference. Longitude is measured east or west of prime meridian. The grid of latitude and longitude over the globe is known as graticule. The intersection point of the equator and the prime meridian is the origin (0, 0) of the graticule.

Coordinate measurement

The geographic coordinates are measured in angles. The angle measurement can be understood as per following:
A full circle has 360 degrees

1 circle = 360°

A degree is further divided into 60 minutes

1° = 60′

A minute is further divided into 60 seconds

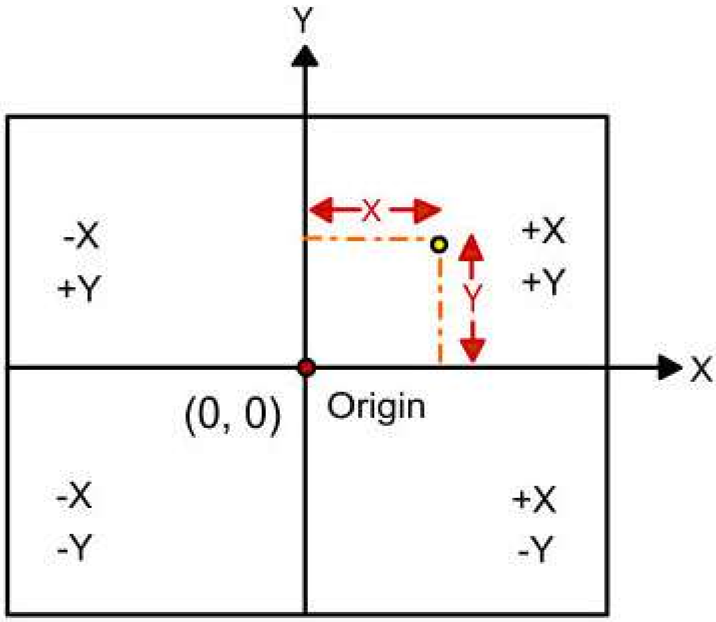
1′ = 60″

An angle is expressed in Degree Minute Second.
While writing coordinates of a location, latitude is followed by longitude. For example, coordinates of Delhi is written as 28° 36′ 50″ N, 77° 12′ 32″ E.
Decimal Degree is another format of expressing the coordinates of a location. To convert a coordinate pair from degree minute second to decimal degree following method is adopted:

$$
\begin{aligned}
28^\circ\, 36'\, 50'' &= 28 + (36*1/60) + (50 *1/60*1/60) \\
&= 28 + 0.6 + 0.0138 \\
&= 28.6138
\end{aligned}
$$

We have 28 full degrees, 36 minutes - each 1/60 of a degree, and 50 seconds - each 1/60 of 1/60 of a degree
While writing coordinates of a location, latitude is followed by longitude. For example, coordinates of Delhi is written as
Similarly 77° 12′ 32″ can be written as 77.2088. So, we can write coordinates of Delhi in decimal degree format as: 28.6138 N, 77.2088 E

Projected Coordinate system
A projected coordinate system is defined as two dimensional representation of the Earth. It is based on a spheroid geographic coordinate system, but it uses linear units of measure for coordinates. It is also known as Cartesian coordinate system.
In such a coordinate system the location of a point on the grid is identified by (x, y) coordinate pair and the origin lies at the centre of grid. The x coordinate determines the horizontal position and y coordinate determines the vertical position of the point.



In such a coordinate system the location of a point on the grid is identified by (x, y) coordinate pair and the origin lies at the centre of grid. The x coordinate determines the horizontal position and y coordinate determines the vertical position of the point.

Map Projection

Map projection is a mathematical expression using which the three-dimensional surface of earth is represented in a two dimensional plane. The process of projection results in distortion of one or more map properties such as shape, size, area or direction.
A single projection system can never account for the correct representation of all map properties for all the regions of the world. Therefore, hundreds of projection systems have been defined for accurate representation of a particular map element for a particular region of the world.

Classification of Map Projections

Map projections are classified on the following criteria:

1. Method of construction
2. Development surface used
3. Projection properties
4. Position of light source
5. Method of Construction

The term map projection implies projecting the graticule of the earth onto a flat surface with the help of shadow cast. However, not all of the map projections are developed in this manner. Some projections are developed using mathematical calculations only. Given below are the projections that are based on the method of construction:
Perspective Projections : These projections are made with the help of shadow cast from an illuminated globe on to a developable surface

Non Perspective Projections : These projections do not use shadow cast from an illuminated globe on to a developable surface. A developable surface is only assumed to be covering the globe and the construction of projections is done using mathematical calculations.

Development Surface

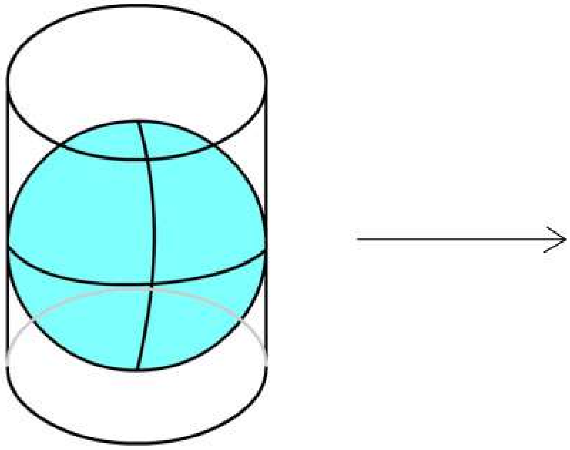
Projection transforms the coordinates of earth on to a surface that can be flattened to a plane without distortion (shearing or stretching). Such a surface is called a developable surface. The three basic projections are based on the types of developable surface and are introduced below:

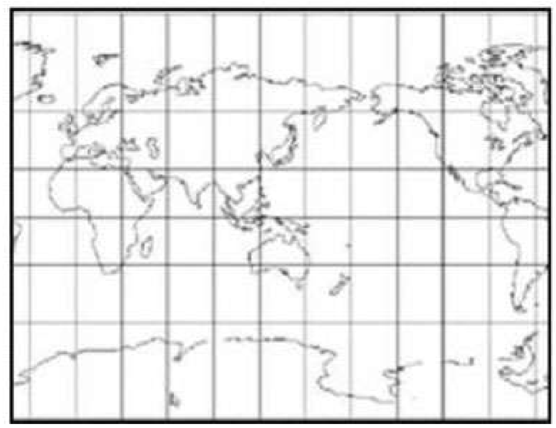
1. Cylindrical Projection

It can be visualized as a cylinder wrapped around the globe. Once the graticule is projected onto the cylinder, the cylinder is opened to get a grid like pattern of latitudes and longitudes.

The longitudes (meridians) and latitudes (parallels) appear as straight lines

Length of equator on the cylinder is equal to the length of the equator therefore is suitable for showing equatorial regions.





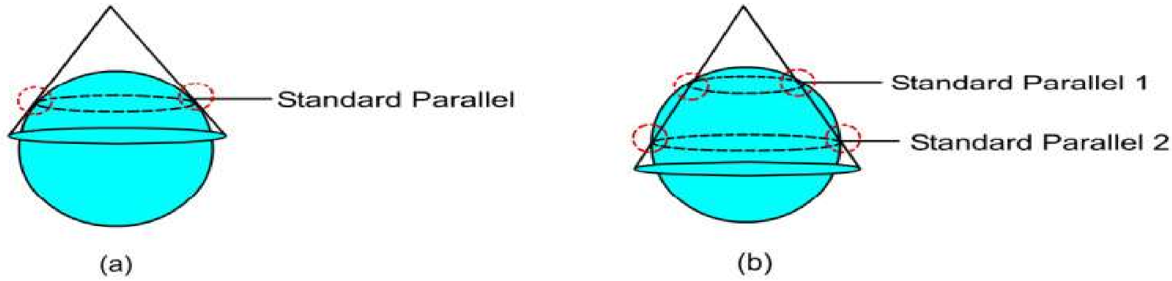
2. Conic Projection

It can be visualized as a cone placed on the globe, tangent to it at some parallel.

After projecting the graticule on to the cone, the cone is cut along one of the meridian and unfolded. Parallels appear as arcs with a pole and meridians as straight lines that converge to the same point.

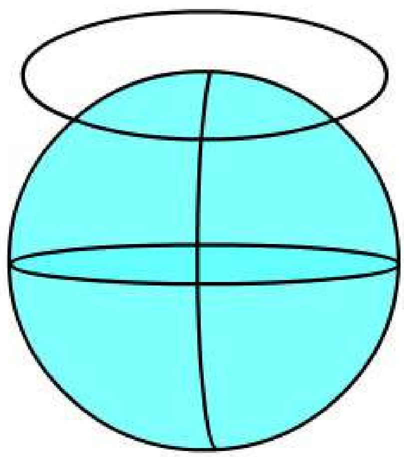
It can represent only one hemisphere, at a time, northern or southern.

Suitable for representing middle latitudes.



3. Azimuthal/Zenithal Projection

It can be visualized as a flat sheet of paper tangent to any point on the globe The sheet will have the tangent point as the centre of the circular map, where meridians passing through the centre are straight line and the parallels are seen as concentric circle. Suitable for showing polar areas



Projection Properties

According to properties map projections can be classified as:

Equal area projection: Also known as homolographic projections. The areas of different parts of earth are correctly represented by such projections.

True shape projection: Also known as orthomorphic projections. The shapes of different parts of earth are correctly represented on these projections.

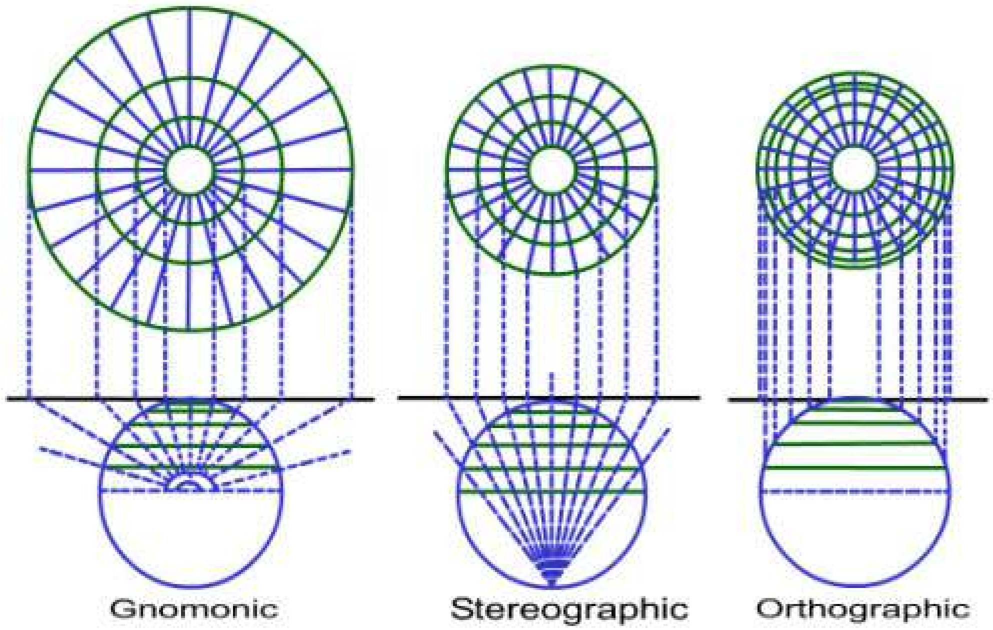
True scale or equidistant projections: Projections that maintain correct scale are called true scale projections. However, no projection can maintain the correct scale throughout. Correct scale can only be maintained along some parallel or meridian.

Position of light source

Placing light source illuminating the globe at different positions results in the development of different projections. These projections are:
Gnomonic projection: when the source of light is placed at the centre of the globe
Stereographic Projection: when the source of light is placed at the periphery

of the globe, diametrically opposite to the point at which developable surface touches the globe.

Orthographic Projection: when the source of light is placed at infinity from the globe opposite to the point at which developable surface touches the globe.



GIS is a set of tool that allows for the processing of spatial data into information.

Components of a GIS

A GIS can be divided into five components: People, Data, Hardware, Software, and Procedures. All of these components need to be in balance for the system to be successful. No one part can run without the other.

People

The people are the component who actually makes the GIS work. They include a plethora of positions including GIS managers, database administrators, application specialists, systems analysts, and programmers. They are responsible for maintenance of the geographic database and provide technical support. People also need to be educated to make decisions on what type of system to use. People associated with a GIS can be categorized into: viewers, general users, and GIS specialists.

- Viewers are the public at large whose only need is to browse a geographic database for referential material. These constitute the largest class of users.
- General Users are people who use GIS to conducting business, performing professional services, and making decisions. They include facility managers, resource managers, planners, scientists, engineers, lawyers, business entrepreneurs, etc.

- GIS specialists are the people who make the GIS work. They include GIS managers, database administrators, application specialists, systems analysts, and programmers. They are responsible for the maintenance of the geographic database and the provision of technical support to the other two classes of users. (Lo, 2002)

Procedures

Procedures include how the data will be retrieved, input into the system, stored, managed, transformed, analyzed, and finally presented in a final output. The procedures are the steps taken to answer the question needs to be resolved. The ability of a GIS to perform spatial analysis and answer these questions is what differentiates this type of system from any other information systems.

The transformation processes includes such tasks as adjusting the coordinate system, setting a projection, correcting any digitized errors in a data set, and converting data from vector to raster or raster to vector. (Carver, 1998)

Hardware

Hardware consists of the technical equipment needed to run a GIS including a computer system with enough power to run the software, enough memory to store large amounts of data, and input and output devices such as scanners, digitizers, GPS data loggers, media disks, and printers. (Carver, 1998)

Software

There are many different GIS software packages available today. All packages must be capable of data input, storage, management, transformation, analysis, and output, but the appearance, methods, resources, and ease of use of the various systems may be very different. Today's software packages are capable of allowing both graphical and descriptive data to be stored in a single database, known as the object-relational model. Before this innovation, the geo-relational model was used. In this model, graphical and descriptive data sets were handled separately. The modern packages usually come with a set of tools that can be customized to the users needs (Lo, 2002).

Data

Perhaps the most time consuming and costly aspect of initiating a GIS is creating a database. There are several things to consider before acquiring geographic data. It is crucial to check the quality of the data before obtaining it. Errors in the data set can add many unpleasant and costly hours to implementing a GIS and the results and conclusions of the GIS analysis most likely will be wrong.

Fundamental operations of GIS

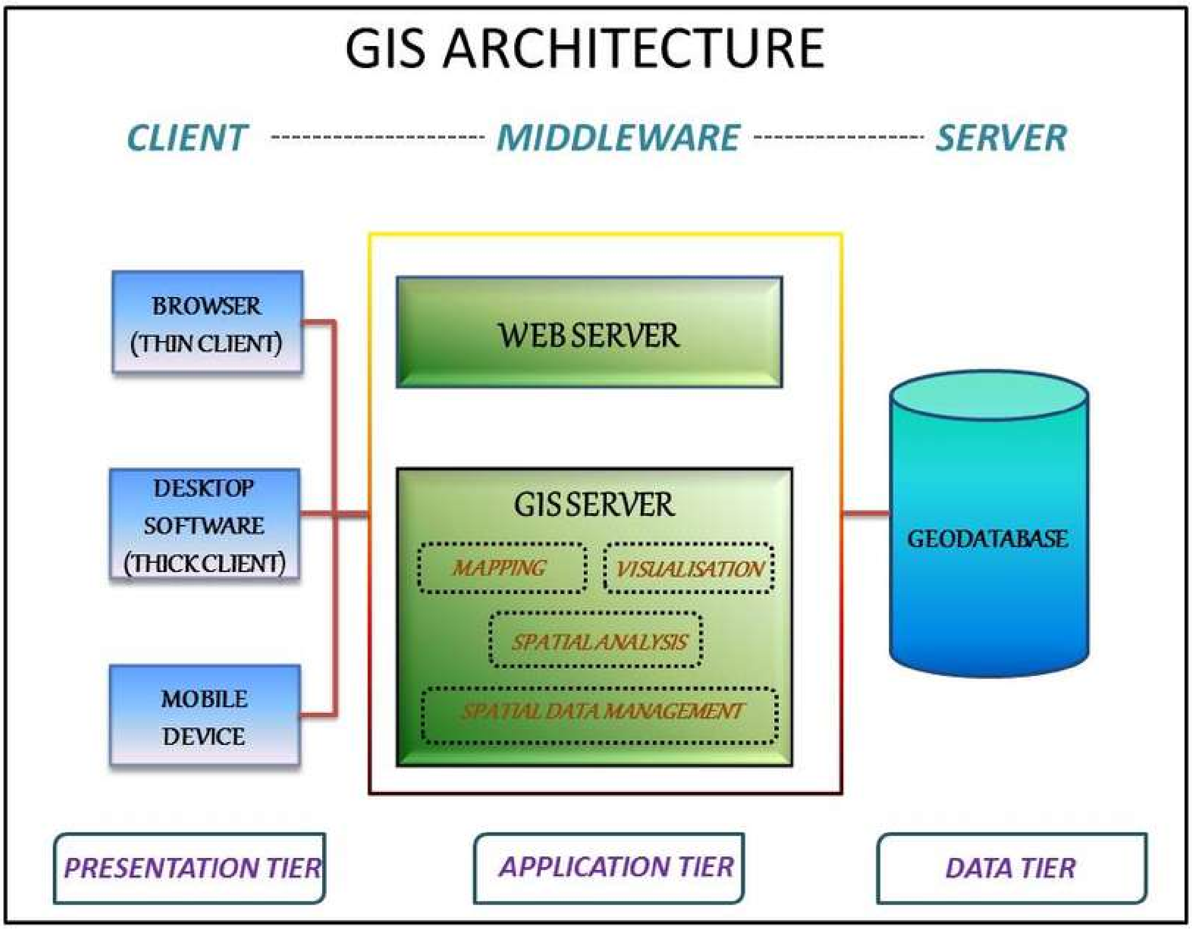
1. Reclassification operations transform the attribute information associated with a single map coverage.
2. Overlay operations involve the combination of two or more maps according to boolean conditions and may result in the delineation of new boundaries.

3. Distance and connectivity measurement include both simple measure of interpoint distance and more complex operations such as the construction of zones of increasing transport cost away from specified locations, and
4. Neighbourhood characterisation involves the values to a location both summary and mean measures of avariable, and include smoothing and enhancement filters. Sequences or such manipulation operations have become known as 'cartographic modelling'.

Theoretical framework of GIS
Based on the way in which the data is transformed:

1. Traditional Cartographic process
2. Based on GIS operation.

GIS Architecture



GIS Workflow
5 elements

1. Data Acquisition
2. Pre-processing
   a. Format Conversion
   b. Data Reduction & Generalization
   c. Error Detection & Editing

    d. Merging the points into lines and lines into Polygons
    e. Edge-matching & Tiling
    f. Rectification & Registration
    g. Interpolation
    h. Interpretation
3. Data Management
    a. Insert
    b. Update
    c. Delete
    d. Retrieve
4. Manipulation & Analysis
    a. Reclassification & Aggregation
    b. Geometric Operations: Rotation, Scaling, Rectification
    c. Controlled Determination
    d. Data Structure Conversion
    e. Spatial Operation of Connectivity &Neighbourhood Operations
    f. Measurement of Distance & Direction
    g. Statistical Analysis
    h. Modelling
5. Product Generation (Final Outputs from GIS are created)

Data entry & preparation – Spatial data input

Collecting data and creating a GIS database is a time consuming but an important task. There are many sources of geographic data and many ways to enter that data into a GIS. A data pool can be generated by either data capture or data transfer. The data sources are divided into following two main classes:

Primary data
It involves direct measurement of objects and phenomena. Given below is the partial list of primary data:

Remote sensing data capture: Remote sensing refers to the technique of deriving the information about the objects without getting in physical contact with them. The information is derived from the measurements of the amount of electromagnetic (EM) radiations reflected, emitted or scattered from the objects under observation. The response is measured /captured by the sensors deployed in air or in space. The remote sensing data is often talked in terms of spatial, spectral and temporal resolutions.

Aerial photographic data is as important as remote sensing data for a GIS project. Though both aerial photographs and remote sensing images are technically similar, they have few differences as well. The most notable difference is that aerial photographs are captured using analog optical cameras and are then rasterized by scanning a film negative. Now a days digital cameras are being used for aerial photography. The aerial photographs are suitable for surveying and mapping projects.

Both satellite images and aerial photographs can provide stereo imagery from overlapping pairs of images i.e. they can generate a three dimensional model of the earth's surface. The other advantages include global coverage and repetitive monitoring that make these datasets useful for large area projects and short time events.

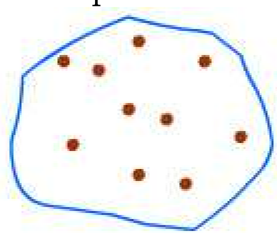
Surveying: Ground surveying is based on the principle of determining the 3D location of a point with the help of angles and distance measured from other known points. Survey starts from a benchmark position. The location of all surveyed points is relative to other points. The traditional surveying involves the use of transits, theodolites, chains and tapes for angle and distance measurement. These days, electro-optical devices called total stations measure both angles as well distance to an accuracy of 1mm. Surveying is a time and resource consuming activity but is the best way of obtaining accurate geographical data.

Sampling

Since it is not practically possible as well as worthwhile to observe the value of a variable at every point throughout the study area we adopt the strategy of sampling. Using sampling we measure subsets of the features in the area that best capture the spatial variation of the concerned attribute over the study area. The following five patterns options may be considered for sampling:

a.Simple random

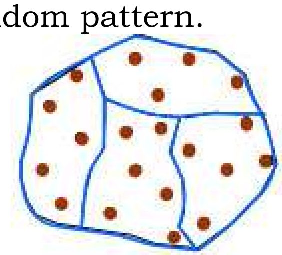
This method ensures that all parts of the project area have an equal chance of being sampled. Project area is divided into a grid with numbered coordinates. A random site is picked by selecting coordinate pairs from a number table and plotting those on the project area map. Each random site is a sample point.



Simple random pattern

b. Stratified random

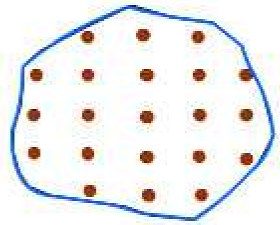
It maintains randomness and at the same time overcomes the chance of an uneven distribution of points among the map classes. Specific numbers of sample points are assigned to each class with respect to its size and significance for the project. Within a class the random sites are generated in the same way as in simple random pattern.



Stratified random pattern

c. Systematic

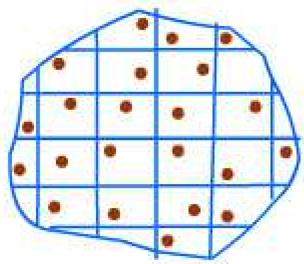
It arranges sample points at equidistant intervals thus forming a grid.
Orientation of the grid is chosen randomly.



Systematic pattern

d. Systematic unaligned

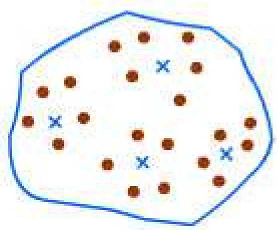
It distributes the project area into a grid and assigns the positions of sample points randomly within the grid cells.



Systematic unaligned pattern

e. Clustered

In this method, nodal points are the centers for clusters of sample points. The nodal locations are selected randomly, stratified by classes, or by identification of accessible sites.



Clustered pattern

GPS (Global Positioning System): GPS is a collection of 27 NAVSTAR satellites orbiting the earth at a height of 12, 500 miles or 20, 200 km. It was originally funded by US Department of Defense and was only used for military purposes but, in the year 2000 it was opened for civilians as well. GPS works on distance and time principal. The GPS satellites transmit radio signals that indicate their exact position in space. The receiver measures the time taken by signal to reach the receiver. Similarly, distance from three or more satellites helps in triangulating the position of the receiver on the earth's surface. As soon as the signal from fourth satellite is received, elevation information is also derived. GPS has led to the development of hundreds of applications affecting every aspect of modern day to day life. Farming, mining, construction, logistics, communication, power etc. are some of the sectors that have started depending heavily on GPS.

Spatial Data Models

Spatial data structures provide the information that the computer requires to reconstruct the spatial data model in digital form. Although some lines act alone and contain specific attribute information that describes their character, other more complex collections of lines called networks add a dimension of attribute characters. Thus not only does a road network contain information about the type of road or similar variables, but it will also indicate, that travel is possible only in a particular direction. This information must be extended to each connecting line segment to advise the user that movement can continue along each segment until the attributes change-perhaps until a one-way street becomes a two-way street. For example, one node might indicate the existence of a stop sign, a traffic signal, or a sign prohibiting U-turns. All these attributes must be connected throughout the network so that the computer knows the inherent real-world relationships that are being modelled within the network. Such explicit information about connectivity and relative spatial relationships is called topology.

Vector data model: A representation of the world using points, lines, and polygons. Vector models are useful for storing data that has discrete boundaries, such as country borders, land parcels, and streets.

Raster data model: A representation of the world as a surface divided into a regular grid of cells. Raster models are useful for storing data that varies continuously, as in an aerial photograph, a satellite image, a surface of chemical concentrations, or an elevation surface

Types of Raster GIS Models

The grid based GIS spatial data can be stored, manipulated, analysed, and referenced basically in anyone of the three methods/models. These three models (Burrough, 1983) are: GRID/LUNAR/MAGI model, IMGRID model and MAP model. All of these models use the grid cell values, their attributes, coverages and corresponding legends. These models are developed depending upon the requirements from time to time. Based on the applications of interest, availability of software's and other related information, anyone of the above models can be selected for the execution of a particular GIS project. There are a number of ways of forcing a computer to store and reference the individual grid cell values, their attributes, coverage names and legends.

1. **GRID Model**

The first and foremost model for the representation of raster data is the GIRD model. The method of storing, manipulating, and analysing the grid based data was first conceptualised by an attempt to deve'lop GRID model. Burrough (1983) used this approach, because each of those early GIS systems used this model. Fig. 8.9 (a) illustrates the GRID model. In this method, each grid cell is referenced and addressed individually and is associated with identically positioned grid cells in all other coverages, rather like a vertical column of grid cells, each dealing with a separate theme. Comparisons between coverages are therefore performed on a single column at a time. For example, to compare soil attributes in one coverage with vegetation attributes in a second coverage, land use/land cover attributes in a third coverage, each X and Y location must be

examined individually. So a soil grid cell at location must be examined individually. So a soil grid cell at location X10-Y10 will be compared to its vegetation counterpart and third layer land use/land cover at location X 10-Y1 O. You might be able to envision this by imagining a geological core in which each rock type is lying directly on top of the next, and to get a picture of the entire study area, it will be necessary to put a large number of cores together.
The advantage of this model is that computational comparison of multiple themes or coverages for each grid cell location is relatively easy. This is a reasonable approach and has proven successful. The main disadvantage is that it limits the efficient examination of relationships of themes to one-to-one relationships within the spatial framework. In other words, it is more inconvenient to compare groups in one coverage to groups in another coverage because each grid cell location must be addressed individually. Second disadvantage is more storage space for the cell data and the representation is vertical rather than horizontal, which would more closely resemble our notion of maps.

2. IMGRID Model

With a slight modification of the checkerboard analog, the second basic raster data model, that is the IMGRID data model, can be illustrated (Fig. 8.9 (b». This model is also used in the early GIS system (Burrough, 1983). Let us assume that the red squares on checkerboard map serve to contain a single attribute, rather than just a theme. Instead, we can use the number 1 (red squares) to repre·sent water and 0 (black squares) to indicate the absence of water. How can we represent a thematic map of land use that contains, say four categories, namely, recreation, agriculture, industry, and residences? Each of these four attributes would have to be separated out as an individual layer. One layer would stand for agriculture only, with 1 's and O's representing the presence or absence of this activity for each grid cell. Recreation, industry, and residences would be represented in the same way, with each variable referenced directly, rather than referencing the grid cell as we did in the GRID/LUNAR/ MAGI data model. Finally, the coverages would be combined vertically, or in column fashion, to produce a single theme or coverage, much as red, yellow, green, and blue printing plates are combined to create a single colour image.
IMGRID system has two major advantages. First, we have a contiguous object that more closely resembles how we think about a map. That is, our primary storage object is a two-dimensional array of numbers, rather than a column of numbers for different themes. Second, we reduce the numbers that must be contained in each coverage to O's and 1 'so This will certainly simplify our computations and will eliminate the need for map legends. Since each variable is uniquely identified, assigning a single attribute value to a single grid cell is possible, and this is a third advantage. Let us assume that a given grid cell partly occupies agriculture and partly recreation and each of these attributes of land use theme is separated out. In such a case, we may encounter difficulties when creating our final thematic coverage if multiple values occur in individual cells. To avoid such problems, we must be able to ensure that each grid cell has only a single value for each variable.

3. MAP Model

The third raster GIS model Map Analysis Package (MAP) model developed by C. Dana Tomlin (Burrough, 1983) formally integrates the advantages of the above

two raster data structure methods. In this data model each thematic coverage is recorded and accessed separately by map name or title. This is accomplished by recording each variable, or mapping unit, of the coverage's theme as a separate number code or label, which can be accessed individually when the coverage is retrieved. The label corresponds to a portion of the legend and has its own symbol assigned to it. In this way, it is easy to perform operation on individual grid cells and groups of similar grid cells, and the resolution changes in value require rewriting only a single number per mapping unit, thus simplifying the computations. The overall major improvement is that the MAP method allows ready manipulation of the data in a many-to-one relationship of the attribute values and the sets of grid cells.
The MAP data model is compatible to almost all computer systems from its original mainframe version to Macintosh and PC versions and modern UNIX-based workstation versions. It can be used as a teaching version of GIS as it is very flexible and also becomes a major module in commercial GIS packages like ARC/INFO.

Vector GIS Models

Vector data structures allow the representation of geographic space in an intuitive way reminiscent of the familiar analog map. The geographic space can be represented by the spatial location of items or attributes which are stored in another file for later access. Fig. 8.5 shows how the different entity, namely, points, lines, and areas can be defined by coordinate geometry. Like the raster spatial data model, there are many potential vector data models that can be used to store the geometric representation of entities in the computer.
The two basic types of vector data models are (i) spaghetti model, and (ii) topological model.

1. **Spaghetti Model**

The simplest vector data structure that can be used to reproduce a geographical image in the computer is a file containing (x, y) coordinate pairs that represent the location of individual point features. The shortest spaghetti can be represented as a point, collection of a number of point spaghettis for a line entity and collections of line segments that come together at the beginning and ending of surrounding areas form an area entity. Each entity is a single, logical record in the computer, coded as variable length strings of (x, y) coordinate pairs. Let us assume that two polygons lie adjacent to each other in a thematic coverage. These two adjacent polygons must have separate pieces of spaghetti for adjacent sides. That is, no two adjacent polygons share the same string of spaghetti. Each side of polygon is uniquely defined by its own set of lines and coordinate pairs. In this model of representing vector data, all the spaghetties are recorded separately for polygons. But in the computer they should have the same coordinates.
Topological Models
In order to use the data manipulation and analysis subsystem more efficiently and obtain the desired results, to allow advanced analytical techniques on GIS data and its systematic study in any project area, much explicit spatial information is to be created. The topological data model incorporates solutions to some of the frequently used operations in advanced GIS analytical

techniques. This is done by explicitly recording adjacency information into the basic logical entity in topological data structures, beginning and ending when it contacts or intersects another line, or when there is a change in the direction of the line. Each line then has two sets of numbers: a pair of coordinates. and an associated node number. The node is the intersection of two or more lines, and its number is used to refer to any line to which it is connected. In addition, each line segment, called a link, has its own identification number that is used as a pointer to indicate the set of nodes that represent its beginning and ending polygon. These links also have identification codes that relate polygon numbers to see which two polygons are adjacent to each other along its length. In fact, the left and right polygon are also stored explicitly, so that even this tedious step is eliminated.
There are a number of topological vector data models. Out of the available models, three models are very common in use. These three models are: (a) GBFI DIME model created by US Department of Commerce, Bureau of the Census, 1969 (b) TIGER model (Marx, 1986) and (c) POLYVERT (Peuquet, 1984).

2. **GBF/DIME Topological Vector Model**

The best-known topological data model is the GBF/DIME (Geographical Base File/Dual independent Map Encoding) model created by the US Bureau of the Census to automate the storage of street map data for the decennial census (US Department of Commerce, Bureau of the Census, 1969). GBF/DIME models were designed to incorporate topological information about urban areas for use in demographic analyses (Cooke, 1987) and were created by graph theory. In this case the straight-line segment ends when it either changes direction or intersects another line, and the nodes are identified with codes. In addition to the basic topological model, the GBF/DIME model assigns a directional code in'the form of a 'From node and a To node,' that is, a low-value node to a high-value node in the sequence.
TIGER Topological Vector Model
TIGER stands for Topologically Integrated Geographic Encoding and Referencing system. This model does not depend upon the graph theory designed for use in the 1990 US census. In this system, points, lines, and areas can be explicitly addressed, and therefore census blocks can be retrieved directly by block number rather than by relying on the adjacency information contained in the links. Real-world features such as meandering streams and irregular coastlines are given a graphic portrayal more representative of their true geographic shape. Thus TIGER files are more generally used in research which is not related to census.

3. **POL YVRT Topological Vector Model**

POLYVRT developed by Peucker and Chrisman (1975) and later implemented at the Harvard Laboratory for Computer Graphics was called the POL YVRT (POLYgon con VERT) model. In this method of representing vector data, each type of geographic entity is stored separately. These separate objects are then linked in a hierarchical data structure with pOints relating to lines, which in turn are related to polygons through the use of pOinters. Each collection of line segments, is collectively called chains in this explicit directional information in the form of To-From nodes as well as left-right polygons.

Raster and Vector data

Raster data is made up of pixels (or cells), and each pixel has an associated value. Simplifying slightly, a digital photograph is an example of a raster dataset where each pixel value corresponds to a particular colour. In GIS, the pixel values may represent elevation above sea level, or chemical concentrations, or rainfall etc. The key point is that all of this data is represented as a grid of (usually square) cells. The difference between a digital elevation model (DEM) in GIS and a digital photograph is that the DEM includes additional information describing where the edges of the image are located in the real world, together with how big each cell is on the ground. This means that your GIS can position your raster images (DEM, hillshade, slope map etc.) correctly relative to one another, and this allows you to build up your map.

Vector data consists of individual points, which (for 2D data) are stored as pairs of (x, y) co-ordinates. The points may be joined in a particular order to create lines, or joined into closed rings to create polygons, but all vector data fundamentally consists of lists of co-ordinates that define vertices, together with rules to determine whether and how those vertices are joined.

Advantages : Data can be represented at its original resolution and form without generalization. Graphic output is usually more aesthetically pleasing (traditional cartographic representation); Since most data, e.g. hard copy maps, is in vector form no data conversion is required. Accurate geographic location of data is maintained. Allows for efficient encoding of topology, and as a result more efficient operations that require topological information, e.g. proximity, network analysis.

Disadvantages: The location of each vertex needs to be stored explicitly. For effective analysis, vector data must be converted into a topological structure. This is often processing intensive and usually requires extensive data cleaning. As well, topology is static, and any updating or editing of the vector data requires re-building of the topology. Algorithms for manipulative and analysis functions are complex and may be processing intensive. Often, this inherently limits the functionality for large data sets, e.g. a large number of features. Continuous data, such as elevation data, is not effectively represented in vector form. Usually substantial data generalization or interpolation is required for these data layers. Spatial analysis and filtering within polygons is impossible.

Raster Data
Advantages : The geographic location of each cell is implied by its position in the cell matrix. Accordingly, other than an origin point, e.g. bottom left corner, no geographic coordinates are stored. Due to the nature of the data storage technique data analysis is usually easy to program and quick to perform. The inherent nature of raster maps, e.g. one attribute maps, is ideally suited for mathematical modeling and quantitative analysis. Discrete data, e.g. forestry stands, is accommodated equally well as continuous data, e.g. elevation data, and facilitates the integrating of the two data types. Grid-cell systems are very

compatible with raster-based output devices, e.g. electrostatic plotters, graphic terminals.

Disadvantages: The cell size determines the resolution at which the data is represented.; It is especially difficult to adequately represent linear features depending on the cell resolution. Accordingly, network linkages are difficult to establish. Processing of associated attribute data may be cumbersome if large amounts of data exists. Raster maps inherently reflect only one attribute or characteristic for an area. Since most input data is in vector form, data must undergo vector-to-raster conversion. Besides increased processing requirements this may introduce data integrity concerns due to generalization and choice of inappropriate cell size. Most output maps from grid-cell systems do not conform to high-quality cartographic needs.

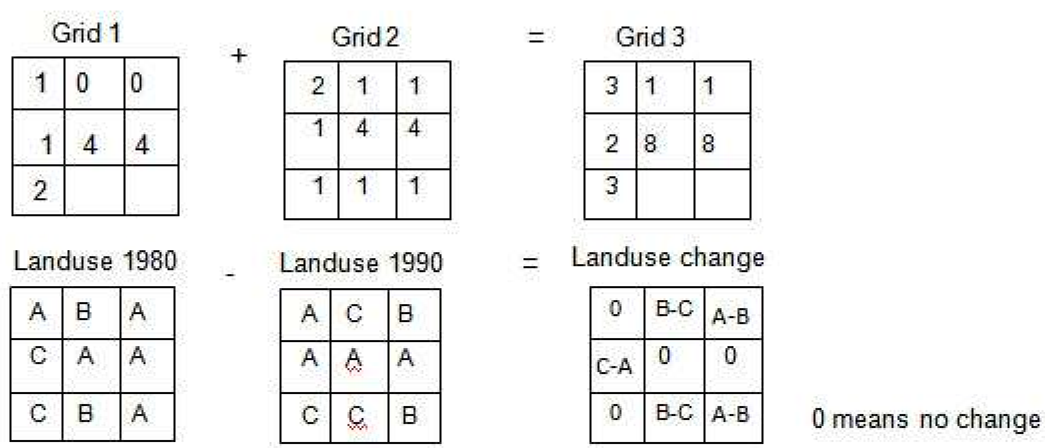
Local Operations

Local functions process a grid on a cell-by-cell basis, that is, the output value of each cell depends on the values of corresponding cells in the rasters input for the analysis. The following are the examples of the local operations.

Arithmetic Operation

Grids can undergo a range of arithmetic operations such as addition, subtraction, multiplication, and division. If the data in grids (operands) is in the form of integer then the data in the resultant grid after any mathematical operation would also be integer.

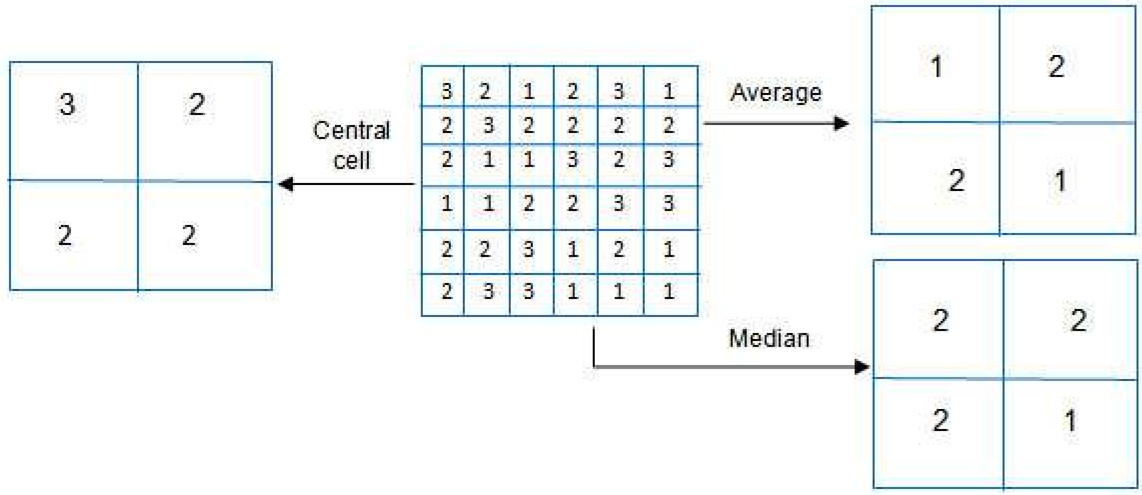
Only in one case, when any integer is divided by zero the corresponding resultant cell will be undefined and are assigned to no data. No data cells always remain No data in arithmetic operations.



Focal Operations (neighborhood analysis)

The value of a cell in the output raster depends upon the value of the corresponding cells and their neighbouring cells in the input rasters. The neighbourhood for a cell is generally taken as a 3×3 matrix (window) in which the cell itself occupies the centre and is surrounded by the others eight cells.

With each cell in the input getting processed, the neighbourhood window keeps moving.



Zonal Operations

Zonal functions process grid in such a manner that cells of same zone are analyzed together. A zone may or may not be contiguous. The output value for each location depends upon the value of cell at that location and the association the location has within a zone.

Global Operations

The value of each cell in the output raster is a function of the entire grid.

UNIT –IV

Syllabus:

Global Positioning System (GPS)

Space, Control and User segments of GPS. Indian Systems (IRNSS, GAGAN) Development of GPS surveying techniques, Navigation with GPS.

Learning Material

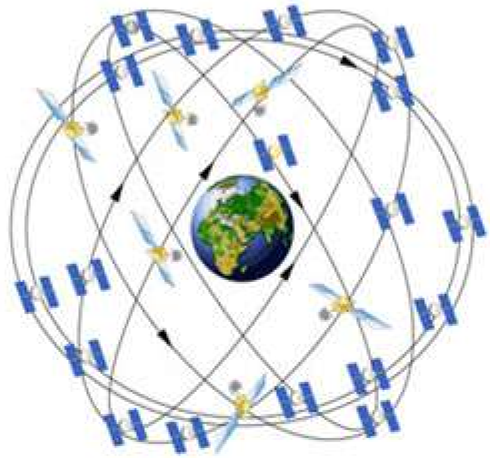
GPS is a satellite based navigation system.The present NAVigation System with Timing And Ranging (NAVSTAR) GPS, belonging to USA that makes use of known positions of satellites in space to determine unknown positions on land, sea, air and in space. It is 24 hours, all weather space based navigation system to accurately determine position, velocity and time anywhere on or near the earth.

The satellites or space vehicles emit signals that can be tracked by the GPS receivers for positioning and navigational purposes. The positioning accuracy ranges from ± 100 m to a few mm depending upon the type of receivers, surveying methods and techniques in post processing of data. The position computed is referenced to a mathematical ellipsoid, the WGS-84.

The GPS system consists of three major segments explained below:

a. Space Segment

It consists of an all weather global system of 24 satellites orbiting the earth every 12 hours in 6 orbital planes at an altitude of approximately 20,200 km.



GPS Constellation

The six equally-spaced orbital planes are inclined at 55° to the equator each having four "slots" for the satellites. The 24-slot arrangement ensures that from any point on the earth a GPS receiver can view at least four satellites.

The GPS satellites are powered primarily by solar panels, with Ni-Cd batteries providing secondary power. On board GPS satellites are the atomic clocks that provide accurate time.

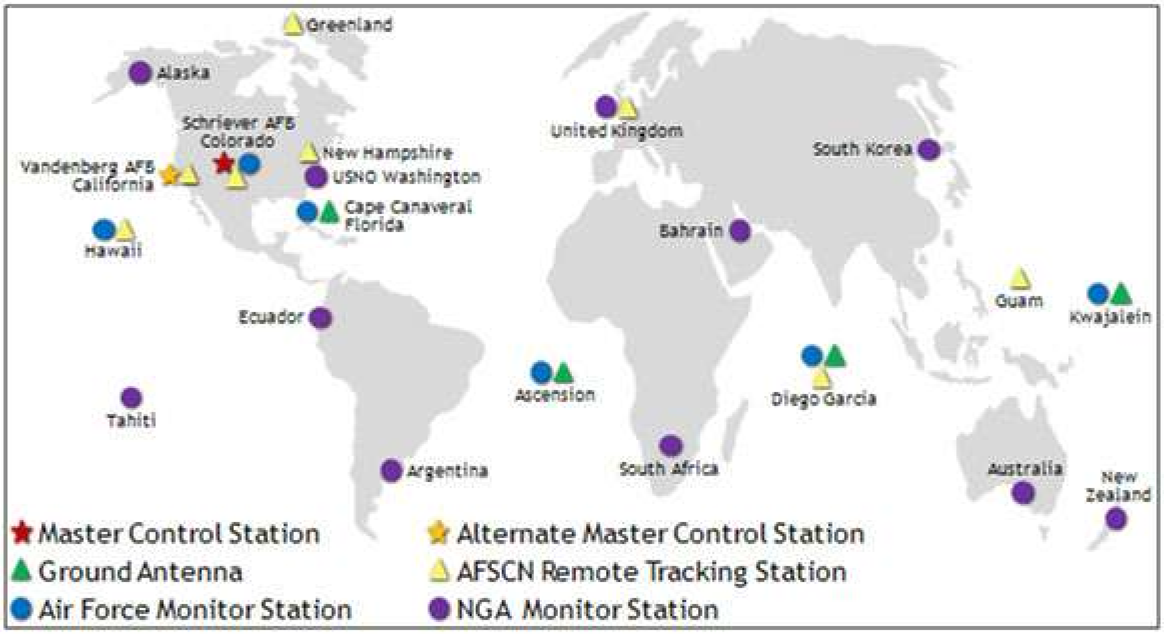
GPS satellites transmit two radio signals, viz. L1 (1575.42 MHz) and L2 (1227.6 MHz). L1 carries a precise (P) code and a coarse/acquisition (C/A) code. L2 carries only the P code. Civilian GPS uses the L1 frequency. The P code is normally encrypted so that only the C/A code is available to civilian users. The signals can pass through clouds and glass but can't penetrate solid objects such as buildings and mountains.

There are often more than 24 operational satellites as new ones are launched to replace the older satellites but these extra satellites are not considered part of the core constellation.

b. Control Segment

GPS control segment is a network of ground facilities that track the GPS satellites, monitor their transmissions, and send commands and data to the constellation. The NAVSTAR control segment has a master control station, an alternate master control station, 12 command and control antennas, and 16 monitoring sites. (See the map for locations)

The master control station in Colorado give commands and controls the GPS constellation. It generates and uploads navigation messages and ensures proper functioning of the satellite constellation.



Control Segment

(Image source: *http://www.gps.gov/systems/gps/control/)*

Monitor stations collect atmospheric data and navigation signals.They track the GPS satellites and channel their observations back to the master control station.

Ground antennas are used to communicate with the GPS satellites for command and control purposes.

c. User Segment

The user segment consists of GPS receivers and the users.

How does the GPS work?

Principle: GPS works on the principle of trilateration i.e. determining absolute or relative locations of points based on the distances to at least three known positions.

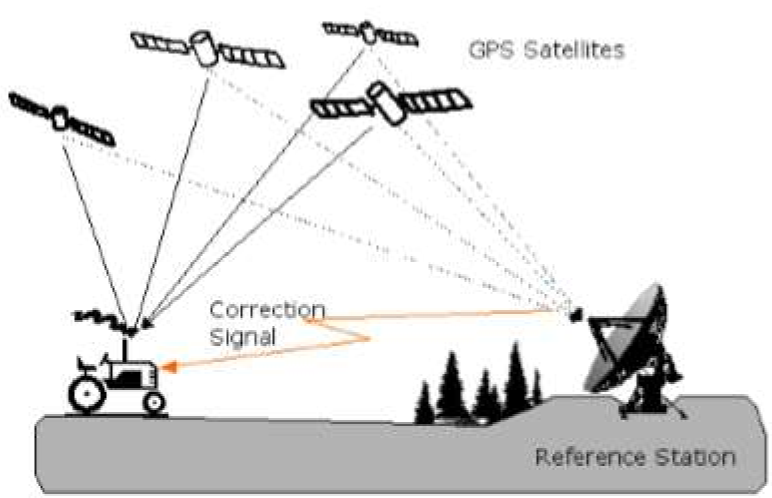
Determining the location of a receiver

GPS receiver calculates its distance from a satellite by measuring how long a signal from the satellite takes to reach it. It is implied that the receiver is located somewhere on the surface of an imaginary sphere centered at the satellite.

Differential GPS

A single GPS receiver can achieve accuracies of approximately 10 meters. One can improve the accuracy of GPS navigation from 1 or 2 meters to a few centimeters by using differential GPS (DGPS).

DGPS is based on the principle that any two receivers within a few hundred kilometers of distance will have the same amount of errors contributed by atmospheric disturbances since their signals travel almost the same distance in atmosphere. DGPS works through two receivers one of which is stationary and the other that moves to make position measurements. The GPS receiver that is set upon a precisely known location is known as base or reference station and the other that moves is known as roving receiver. The base station receiver calculates its position based on satellite signals and compares this location with the known location. The difference obtained is applied to the data recorded by the second GPS receiver. The corrected information can be applied to data from the roving receiver in field in real time or through post processing after the data is captured.



Working of DGPS

Applications of GPS

GPS is an essential element of the global information infrastructure. It is free, open and so dependable that it makes its presence in everything from wrist watches to shipping containers. One may find GPS in sectors such as farming, construction, mining, surveying, and logistics.

The benefits arising from the use of GPS in various fields are mentioned below:

Agriculture

Allows accurate field navigation, and maximum ground coverage in the shortest possible time.

Enhancement of crop productivity by having precision soil sampling, correct estimation of variation in chemical applications and planting density.

Environment

Environmental disasters such as fires and oil spills can be tracked accurately.

GPS tracking and mapping to facilitate monitoring and preservation of endangered species.

Aviation

Free, continuous and accurate positioning information of flights on a global basis.Safe and fuel-efficient routes for airspace service providers.

Public Safety & Disaster Relief

Helps in mapping the disaster affected regions. Can provide positional information about individuals with mobile phones in case of emergency.

Surveying & Mapping

Provides significant productivity gains over traditional surveying by eliminating many of its inherent limitations

Allows surveyors to work uninterrupted in periods of poor weather conditions.

GPS Surveying Techniques

There are wide variety of GPS applications, which is matched by a similar diversity of user equipment and techniques. Nevertheless, the most fundamental classification system for GPS technique is based on the type of observable that is tracked (a) Civilian Navigation / positioning receivers using C/A code and L1 frequency (b) Military navigation / positioning receivers using the satellite P(Y) – code on both L – band frequencies (c) Single frequency (L2) carrier phase tracking receivers (d) dual frequency carrier phase tracking receivers. When these classes of hardware are used in the appropriate manner for relative positioning, the accuracy that is achieved ranges from a few metres in case of standard pseudo range based techniques, to the sub centimetre level in case of carrier phase based techniques. Although Single Point Positioning (SPP) accuracy of 5-10m is now possible, it is assumed that for most geo spatial applications only relative positioning are of relevance.

The following classes of relative positioning techniques can therefore be identified.

1. Static and Kinematic GPS surveying techniques: High precision techniques based on post processing of carrier phase measurements

2. Differential GPS (DGPS): instantaneous low to moderate accuracy positioning and mapping technique based on pseudo range measurements.

3. Real – Time Kinematic (RTK): versatile high precision techniques that use carrier phase measurements in an instantaneous positioning mode.

The DGPS & RTK techniques, because they are able to deliver results in real time, are very powerful GPS positioning technologies.

Indian Regional Navigation Satellite System (IRNSS): NavIC

IRNSS is an independent regional navigation satellite system being developed by India. It is designed to provide accurate position information service to users in India as well as the region extending up to 1500 km from its boundary, which is its primary service area. An Extended Service Area lies between primary service area and area enclosed by the rectangle from Latitude 30 deg South to 50 deg North, Longitude 30 deg East to 130 deg East.

IRNSS will provide two types of services, namely, Standard Positioning Service (SPS) which is provided to all the users and Restricted Service (RS), which is an encrypted service provided only to the authorised users. The IRNSS System is expected to provide a position accuracy of better than 20 m in the primary service area.

Some applications of IRNSS are:

1. Terrestrial, Aerial and Marine Navigation
2. Disaster Management
3. Vehicle tracking and fleet management
4. Integration with mobile phones
5. Precise Timing
6. Mapping and Geodetic data capture
7. Terrestrial navigation aid for hikers and travellers
8. Visual and voice navigation for drivers

GLONASS Navigation System

The firsst GLONASS satellite was launched in October 1982. The full constellation consists of 24 satellites in 3 orbit planes at a height of 19,100 km, which have a 64.8 degree inclination to the earth's equator. The orbiting period is 11 hrs 15 minutes. Each satellite transmits on two L frequency groups (L1 group is centered on 1609 MHz and L2 on 1251 MHz). The GLONASS signals carries both P and C/A codes. Some GPS receiver manufacturers have incorporated the capability to receive both GPS and GLONASS signals.

Galileo Navigation System

Galileo is the European programme for a global satellite navigation system under civil control. When fully operational, there will be 30 satellites in three orbital planes at an altitude of 23222 kilometers. Ten satellites will occupy each of three orbital planes inclined at an angle of 56° to the equator. The orbiting period will be of 14 hours. Galileo will provide initial services as of

2014/2015. This will include an initial Open Service for normal navigation applications, an initial Search-And-Rescue Service for rescue operations and an initial Public Regulated Service for use by governmental authorities.

UNIT – V

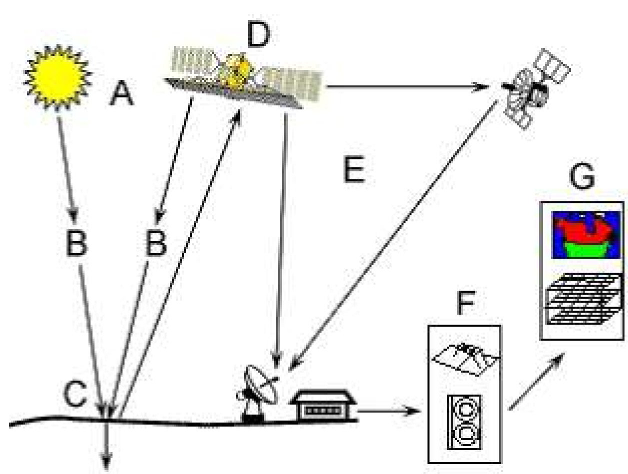
Syllabus:

Basic concepts of remote sensing, Electromagnetic radiation, electromagnetic spectrum, Interaction with atmosphere and target, Sensors and platforms, types of sensors, Airborne remote sensing, Space-borne remote sensing

Learning Material

"**Remote sensing** is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information."

In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. Note, however that remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.



COMPONENTS

1. Energy Source or Illumination (A) - the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.

2. Radiation and the Atmosphere (B) - as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.

3. Interaction with the Target (C) - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.

4. Recording of Energy by the Sensor (D) - after the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.

5. Transmission, Reception, and Processing (E) - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

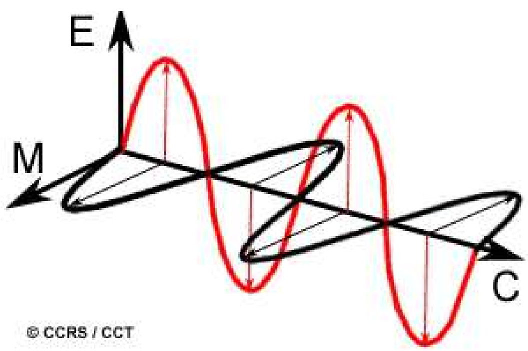
6. Interpretation and Analysis (F) - the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.

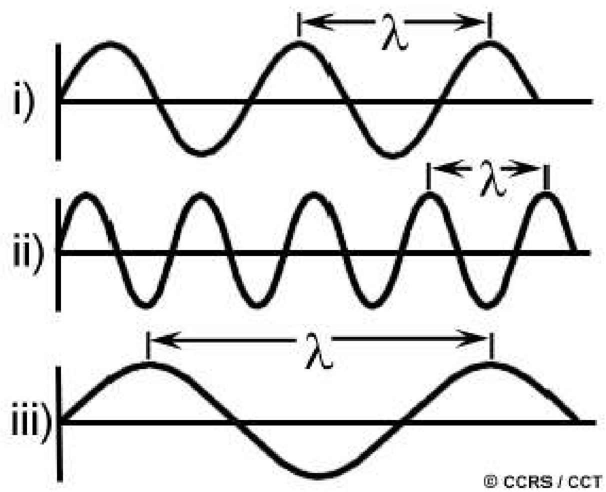
7. Application (G) - the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

These seven elements comprise the remote sensing process from beginning to end.

Wave theory

ELECTROMAGNETIC RADIATION consists of an electrical field(E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c). Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing





The relation between the wavelength (**λ**) and frequency (v) of EMR is based on the following formula

v=c/ λ where c= velocity of light.

Particle theory offers insight into how electromagnetic energy interacts with matter. It suggests that EMR is composed of many discrete units called photons/quanta.

The energy of photon is

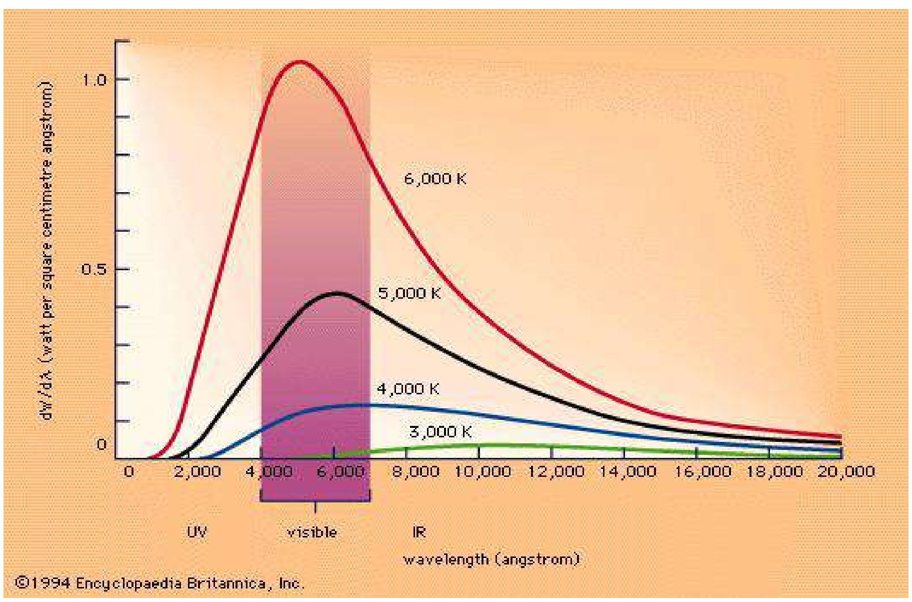
$$Q = hc / \lambda = h \nu$$

Where Q is the energy of quantum, h = Planck's constant

Stefan–Boltzmann law, statement that the total radiant heat energy emitted from a surface is proportional to the fourth power of its absolute temperature. Formulated in 1879 by Austrian physicistJosef Stefan as a result of his experimental studies, the same law was derived in 1884 by Austrian physicist Ludwig Boltzmann from thermodynamic considerations: if *E* is the radiant heat energy emitted from a unit area in one second and *T* is the absolute temperature (in degrees Kelvin), then $E = \sigma T^4$, the Greek letter sigma (σ) representing the constant of proportionality, called the Stefan–Boltzmann constant. This constant has the value 5.6704 × 10^{-8} watt per metre^2·K^4. The law applies only to blackbodies, theoretical surfaces that absorb all incident heat radiation.

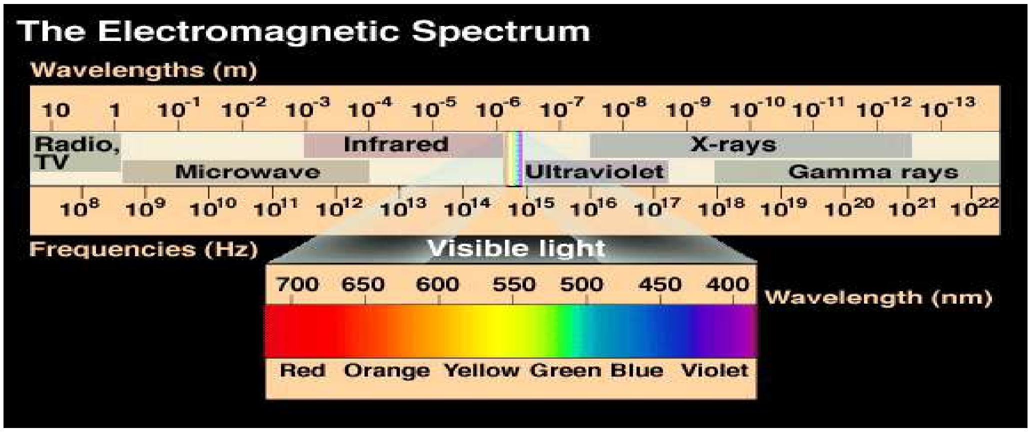
Wien's constant is a physical constant that defines the relationship between the thermodynamic temperature of a black body (an object that radiates electromagnetic energy perfectly) and the wavelength at which the intensity of the radiation is the greatest. The constant is denoted by the Greek lowercase letter sigma with a subscript w (σ_w). It is equal to approximately 2.898 x 10^{-3} meter-kelvin (0.2898 centimeter-kelvin).

The product of the thermodynamic temperature of a black body in kelvin s, and the wavelength of its peak energy output in meter s, is equal to Wien's constant. Thus, as a black body grows hotter, the wavelength of its peak energy output grows shorter



Electromagnetic Spectrum

The electromagnetic spectrum may be defined as the ordering of the radiation according to wavelength, frequency, or energy. The wavelength, denoted by A, is the distance between adjacent intensity maximum (for example) ofthe electromagnetic wave, and consequently, it may be expressed in any unit of length. Most commonly wavelength is expressed in meters (m) or centimeters (cm); microns or micrometers (11 or 11m = 10-4 cm); nanometers (nm = 10-7 cm); or Angstrom units (A = 10-8 cm).



Energy Interaction

Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere. Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused by the mechanisms of scattering and absorption.

- **Atmosphere**

Absorption (Ozone, Carbon Dioxide, Water Vapor)

Scattering (Rayleigh, Mei, Non-Selective)

- Earth Surface

Vegetation

Absorption

Water

Transmission

Land

Reflection (Specular, Diffuse)

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path. How much scattering takes place depends on several factors including the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the atmosphere. There are three (3) types of scattering which take place.

Rayleigh scattering occurs when particles are very small compared to the wavelength of the radiation. These could be particles such as small specks of dust or nitrogen and oxygen molecules. Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths. Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere. The fact that the sky appears "blue" during the day is because of this phenomenon. As sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other (longer) visible wavelengths. At sunrise and sunset the light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths to penetrate the atmosphere.

Mie scattering occurs when the particles are just about the same size as the wavelength of the radiation. Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering. Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast.

The final scattering mechanism of importance is called **nonselective scattering**. This occurs when the particles are much larger than the wavelength of the radiation. Water droplets and large dust particles can cause this type of scattering. Nonselective scattering gets its name from the fact that all wavelengths are scattered about equally.

This type of scattering causes fog and clouds to appear white to our eyes because blue, green, and red light are all scattered in approximately equal quantities (blue+green+red light = white light).

Absorption is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation.

EARTH SURFACE

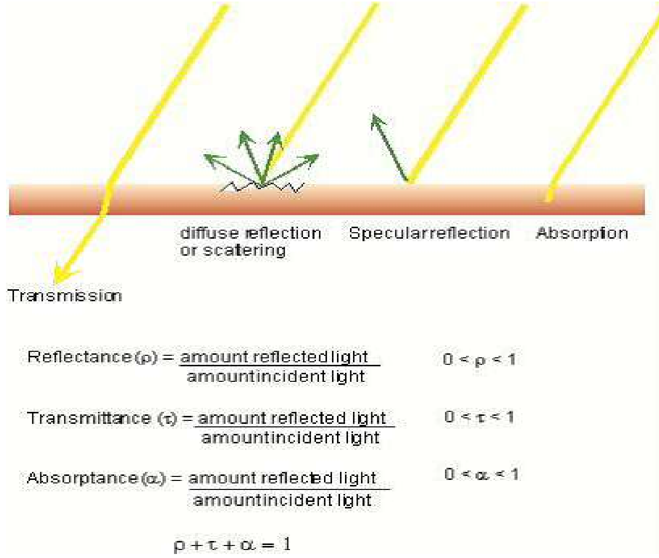
Radiation that is not absorbed or scattered in the atmosphere can reach and interact with the Earth's surface. There are three (3) forms of interaction that can take place when energy strikes, or is incident (I) upon the surface.

These are: absorption (A); transmission (T); and reflection (R). The total incident energy will interact with the surface in one or more of these three ways. The proportions of each will depend on the wavelength of the energy and the material and condition of the feature.

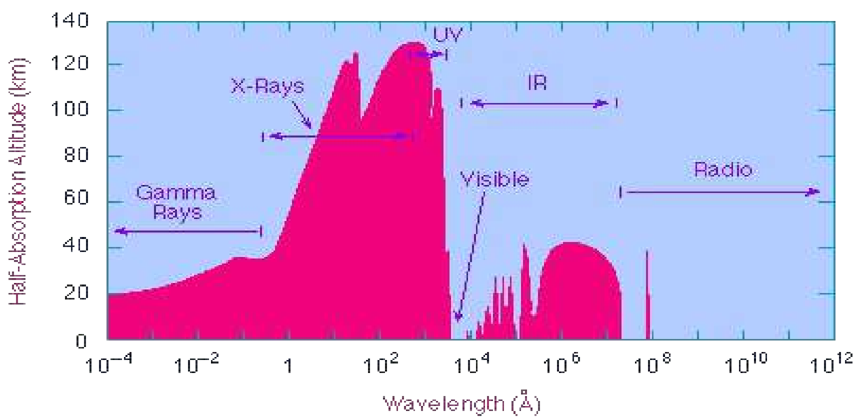
Absorption (A) occurs when radiation (energy) is absorbed into the target while transmission (T) occurs when radiation passes through a target.

Reflection (R) occurs when radiation "bounces" off the target and is redirected. In remote sensing, we are most interested in measuring the radiation reflected from targets. We refer to two types of reflection, which represent the two extreme ends of the way in which energy is reflected from a target: **specular reflection and diffuse reflection**.

When a surface is smooth we get specular or mirror-like reflection where all (or almost all) of the energy is directed away from the surface in a single direction. Diffuse reflection occurs when the surface is rough and the energy is reflected almost uniformly in all directions. Most earth surface features lie somewhere between perfectly specular or perfectly diffuse reflectors. Whether a particular target reflects specularly or diffusely, or somewhere in between, depends on the surface roughness of the feature in comparison to the wavelength of the incoming radiation. If the wavelengths are much smaller than the surface variations or the particle sizes that make up the surface, diffuse reflection will dominate. For example, fine grained sand would appear fairly smooth to long wavelength microwaves but would appear quite rough to the visible wavelengths.



Atmospheric Windows: The general atmospheric transmittance across the whole spectrum of wavelengths is shown in Figure 6. The atmosphere selectively transmits energy of certain wavelengths. The spectral bands for which the atmosphere is relatively transparent are known as atmospheric windows. Atmospheric windows are present in the visible part (.4 μm - .76 μm) and the infrared regions of the EM spectrum. In the visible part transmission is mainly effected by ozone absorption and by molecular scattering. The atmosphere is transparent again beyond about λ= 1mm, the region used for microwave remote sensing.



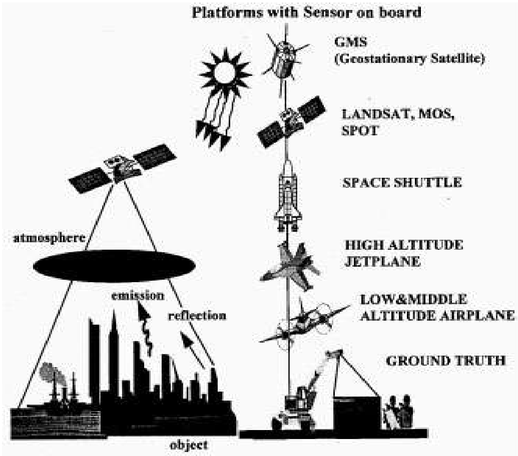
Platforms

A platform is the vehicle or carrier for remote sensors on which they are mounted. Platforms are used to house sensors which obtain data for remote sensing purposes, and are classified according to their heights and events to be monitored.

Permanent ground platforms are typically used for monitoring atmospheric phenomenon although they are also used for long-term monitoring of terrestrial features. Towers and cranes are often used to support research projects where a reasonably stable, long-term platform is necessary. Towers can be built on site and can be tall enough to project through a forest canopy so that a range of measurements can be taken from the forest floor, through the canopy and from above the canopy.

Platforms used for remote sensing are classified into three categories.

- Ground-based
- Airborne
- Space-borne



Ground-Based Platforms

Ground-based sensors are often used to record detailed information about the surface which is compared with information collected from aircraft or satellite sensors. In some cases, this can be used to better characterize the target which is being imaged by these other sensors, making it possible to better understand the information in the imagery.

Ground based sensors may be placed on a ladder, scaffolding, tall building, cherry-picker, crane, etc.

Mobile Hydraulic Platforms

· Carried on vehicles

· Extendable to a height of 15m above the surface.

· At the top of the platform there are:

- Spectral reflectance meters
- Photographic systems
- IR or Microwave scanners

Linked to data loggers in the vans.

Limitation: vehicles limited to roads, and the range is confined to small area along or around the road.

Portable Masts

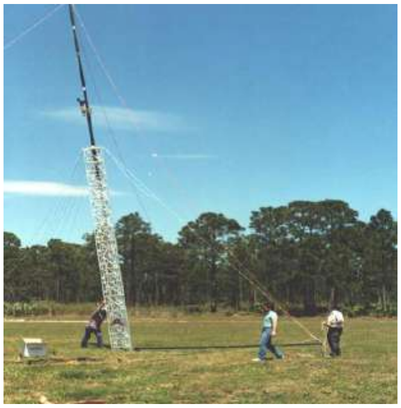
Used to support cameras and scanners

Limitation: could be unstable in windy conditions.

Towers

Can be dismantled and moved from one place to another.

Offer greater rigidity than masts but are less mobile and require more time to erect.



Airborne platforms

Airborne platforms are primarily stable wing aircraft, although helicopters are occasionally used. Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time.

Balloon based missions and measurements

High flying balloons provide an important tool for probing the atmosphere. Such balloon launches form an essential part of high altitude atmospheric research. There are three major advantages of the balloon programme including the following:

1. The balloon has extensive altitude range they can cover. They provide a unique way of covering a broad range of altitudes for in-situ or remote sensing measurements in the stratosphere. Of particular interest is the 22-40 km height range

2. The balloon instruments provide the opportunity for additional, correlative data for satellite based measurements, including both validation ("atmospheric truth") and complementary data (for example, measurement of species not measured from the space based instrument).

3. Balloon based platforms constitute an important and inexpensive venue for testing instruments under development. These can be either potential instruments for unmanned aerial vehicles (UAV) or, in some cases, for satellite based remote sensing instruments.

Here are some remote sensing instruments used in air borne remote sensing.

Radiosonde

Radiosonde, an airborne instrument used for measuring pressure, temperature and relative humidity in the upper air.

The instrument is carried aloft by a meteorological balloon inflated with hydrogen.

The radiosonde has a built-in high frequency transmitter that transmits data from the radiosonde meter and recorded on the ground by a specially designed radiosonde receiver.

Rawinsonde

The rawinsonde is an electronic device used for measuring wind velocity, pressure, temperature and humidity aloft. It is also attached to a balloon and as it rises through the

atmosphere, it measures the velocity of wind at respective altitudes.

Wind Finding Radar

It determines the speed and direction of winds aloft by means of radar echoes. A radar target is attached to a balloon and it is this target that is tracked by ground radar. Bearing and time of interval of the echoes is evaluated by a receiver.

Aircrafts are commonly used as remote-sensing for obtaining Aerial Photographs. In India, four types of aircrafts are being used for remote sensing operations.

DAKOTA : The ceiling height is 5.6 to 6.2 km and minimum speed is 240 km./hr.
AVRO : Ceiling height is 7.5 km and minimum speed is 600 km./hr.
CESSNA : Ceiling height is 9 km. and minimum speed is 350 km./hr.
CANBERRA: Ceiling height is 40 km. and minimum speed is 560 km./hr.

- In airborne remote sensing, downward or sideward looking sensors are mounted on an aircraft to obtain images of the earth's surface.
- An advantage of airborne remote sensing, compared to satellite remote

sensing, is the capability of offering very high spatial resolution images (20 cm or less).

- The disadvantages are low coverage area and high cost per unit area of ground coverage.
- It is not cost-effective to map a large area using an airborne remote sensing system.
- Airborne remote sensing missions are often carried out as one-time operations, whereas earth observation satellites offer the possibility of continuous monitoring of the earth.
- Analog aerial photography, videography, and digital photography are commonly used in airborne remote sensing.
- Synthetic Aperture Radar imaging is also carried out on airborne platforms.
- Analog photography is capable of providing high spatial resolution.
- Digital photography permits real-time transmission of the remotely sensed data to a ground station for immediate analysis.

Aircraft have several useful advantages as platform for remote sensing systems.

- Aircraft can fly at relatively low altitudes thus allowing for sub-meter sensor spatial resolution.
- Aircraft can easily change their schedule to avoid weather problems such as clouds, which may block a passive sensor's view of the ground.
- Last minute timing changes can be made to adjust for illumination from the sun, the location of the area to be visited and additional revisits to that location.
- Sensor maintenance, repair and configuration changes are easily made to aircraft platforms.
- Aircraft flight paths know no boundaries except political boundaries.

Disadvantages of aircraft as platforms in remote sensing.

- Getting permission to intrude into foreign airspace can be a lengthy and frustrating process.
- The low altitude flown by aircraft narrows the field of view to the sensor

requiring many passes to cover a large area on the ground.

- The turnaround time it takes to get the data to the user is delayed due to the necessity of returning the aircraft to the airport before transferring the raw image data to the data provider's facility for preprocessing.

Space borne platforms.

In space, remote sensing is sometimes conducted from the space shuttle or, more commonly, from satellites. Satellites are objects which revolve around another object - in this case, the Earth.

For example, the moon is a natural satellite, whereas man-made satellites include those platforms launched for remote sensing, communication, and telemetry (location and navigation) purposes.

Space borne platforms include the following

Rockets, Satellites and space shuttles. Space borne platforms range from 100 to 36000 km above the earth's surface.

Space shuttle: 250-300 km

Space stations: 300-400 km

Low level satellites: 700-1500 km

High level satellites: About 36000 km

Space borne remote sensing provides the following advantages:

- Large area coverage;
- Frequent and repetitive coverage of an area of interest;
- Quantitative measurement of ground features using radiometrically calibrated sensors;
- Semi automated computerised processing and analysis;
- Relatively lower cost per unit area of coverage.

Salient feature of some important satellite platforms.					
Features	Landsat1,2,3	Landsat 4,5	SPOT	IRS-IA	IRS-IC
Nature	Sun Syn	Sun Syn	Sun Syn	Sun Syn	Sun Syn
Altitude (km)	919	705	832	904	817

Orbital period (minutes)	103.3	99	101	103.2	101.35
inclination (degrees	99	98.2	98.7	99	98.69
Temporal resolution (days)	18	16	26	22	24
Revolutions	251	233	369	307	341
Equatorial crossing (AM)	09.30	09.30	10.30	10.00	10.30
Sensors	RBV, MSS	MSS, TM	HRV	LISS-I, LISS-II	LISS-III, PAN, WIFS

Sensors

The sensor is a device used to acquire a photograph or an image. It will 'sense' and measures the amounts of radiated energy reflected from an object and record it. The types of sensors used are capable of capturing radiation from many different parts of the electromagnetic spectrum which are not visible to the human eye. Although the camera is a type of sensor, the word 'sensor' is normally used for the device used to acquire images in remote sensing.

The amount and range of the radiation that the sensor is capable of sensing, is specific to each type of sensor. When it is required to study and monitor some phenomena, first, scientists have to decide what type of pictures need to be taken of the area. The sensor used for the purpose will depend on the type of picture that needs to be taken

A camera is a sensor used in aerial photography. Black and white aerial photographs are normally taken with either panchromatic film or infrared-sensitive film.

Sensors are broadly of two types:

1. Optical sensor

Optical sensors observe visible lights and infrared rays (near infrared, intermediate infrared, thermal infrared). There are two kinds of observation methods using optical sensors:

a. Visible / Near IR

i. Method to acquire visible light and near infrared rays of sunlight reflected by objects on the ground.

ii. This method cannot be observed during night and cloud cover

b. Thermal Infrared

i. method to acquire thermal infrared rays, which is radiated from land surface heated by sunlight.

ii. This method can be observed during night and cloud cover

2. Microwave sensor.

Microwave sensors receive microwaves, which are longer wavelength than visible light and infrared rays, and observation is not affected by day, night or weather.

There are two types of observation methods using microwave sensor:

a. Active

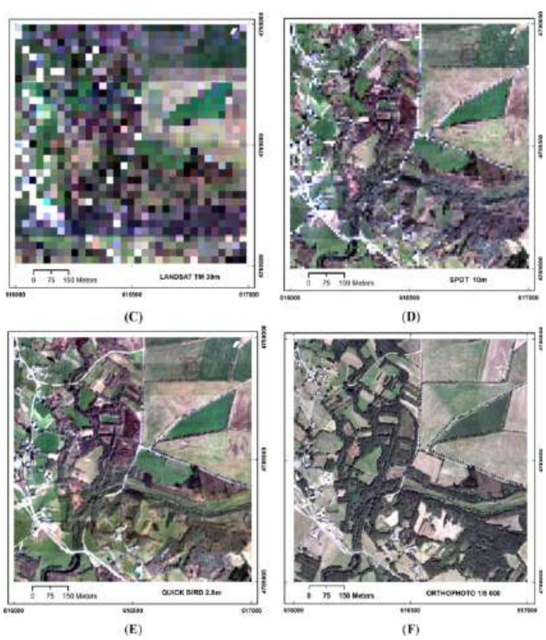
The sensor aboard earth observation satellite emits microwaves and observes microwaves reflected by land surface. It is suitable to observe mountains and valleys.

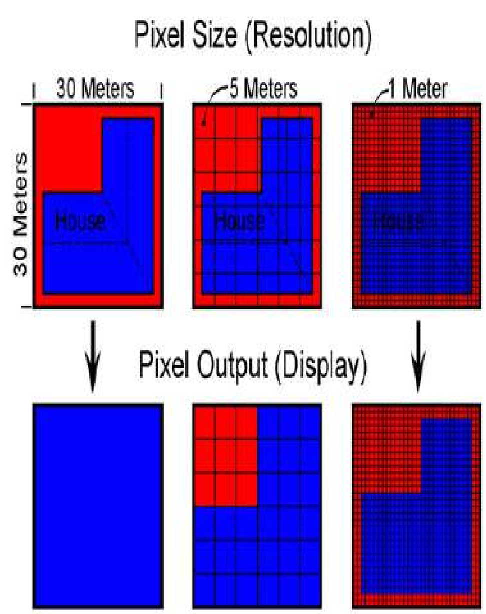
b. Passive

This type observes microwaves naturally radiated from land surface. It is suitable to observe sea surface temperature, snow accumulation, thickness of ice.

Resolution concept

Spatial resolution: It is a measure of the smallest angular or linear separation between two objects that can be resolved by the sensor. The greater the sensor's resolution, the greater the data volume and smaller the area covered. In fact, the area coverage and resolution are inter-dependant and these factors determine the scale of the imagery.

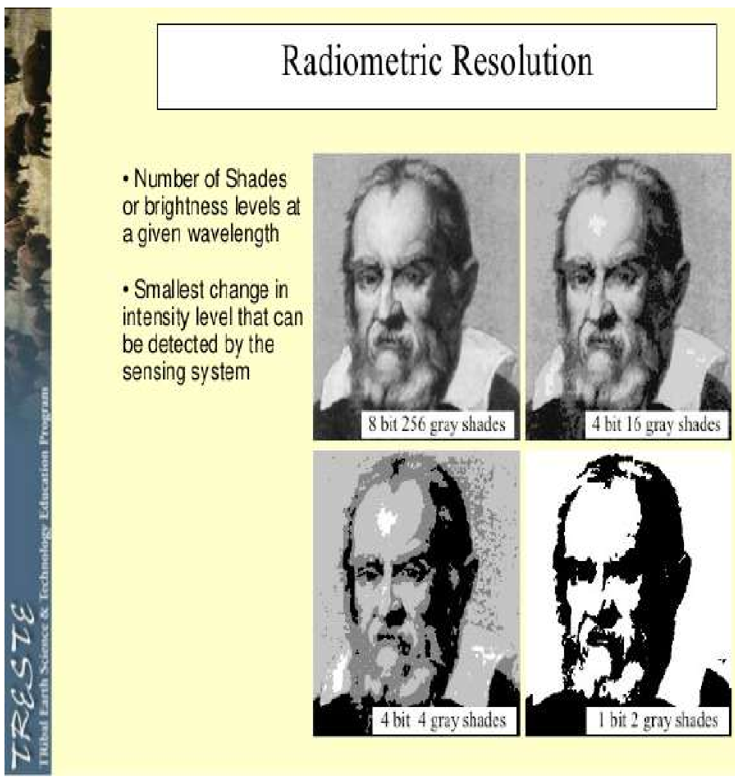




Spectral resolution: It refers to the dimension and number of specific wavelength intervals in the electromagnetic spectrum to which a sensor is sensitive. Narrow bandwidths in certain regions of the electromagnetic spectrum allow the discrimination of various features more easily.

Temporal resolution: It refers to how often a given sensor obtains imagery of a particular area. Ideally, the sensor obtains data repetitively to capture unique discriminating characteristics of the phenomena of interest.

Radiometric sensitivity: It is the capability to differentiate the spectral reflectance/ emittance from various targets. This depends on the number of quantisation levels within the spectral band. In other words, the number of bits of digital data in the spectral band will decide the sensitivity of the sensor.



UNIT – VI

Syllabus:

Photogrammetry and its classification, Process of Photogrammetry, Flight Line Exposure station, Block of photographs, Central Perspective geometry Flying height of a vertical photograph, overlap, side lap. Flight planning, Photogrammetric Imaging Devices, Conversion of aerial to digital format.

Learning Material

Photogrammetry is the science of making measurements from photographs.

The input to photogrammetry is photographs, and the output is typically a map, a drawing, a measurement, or a 3D model of some real-world object or scene. Many of the maps we use today are created with photogrammetry and photographs taken from aircraft.

Types of Photogrammetry

Photogrammetry can be classified several ways but one standard method is to split the field based on camera location during photography. On this basis we have Aerial Photogrammetry, and Terrestrial (or Close-Range) Photogrammetry.

In **Aerial Photogrammetry**, the camera is mounted in an aircraft and is usually pointed vertically towards the ground. Multiple overlapping photos of the ground are taken as the aircraft flies along a flight path. The aircraft traditionally have been fixed wing manned craft but many projects now are done with drones and UAVs. Traditionally these photos were processed in a stereo-plotter (an instrument that lets an operator see two photos at once in a stereo view) but now are often processed by automated desktop systems.

In **Terrestrial and Close-range Photogrammetry**, the camera is located on the ground, and hand held, tripod or pole mounted. Usually this type of photogrammetry is non-topographic - that is, the output is not topographic products like terrain models or topographic maps, but instead drawings, 3D models, measurements, or point clouds. Everyday cameras are used to model and measure buildings, engineering structures, forensic and accident scenes, mines, earth-works, stock-piles, archaeological artifacts, film sets, etc. In the computer vision community, this type of photogrammetry is sometimes called Image-Based Modeling.

Photogrammetric Process:
There are 3 Main Components

1. Image acquisition

Flight Planning

The number of flight lines, their location, the spacing between them, and their orientation depends on the characteristics of the project to be mapped and on the specifications of the flight mission. Specifications which outline how to take the photos, including camera and film requirements, scale, flying heights, end lap, side lap, tilt and crab tolerances, etc.

Selecting an appropriate camera system

The camera is one of the most important types of equipment used in the photogrammetric process as it is the data in which all photogrammetric principles will be applied to. The camera should produce distortion free images in rapid successions in a moving aircraft.

Aerial Films

The image must be recorded on stable film in order to avoid shrinkage or expansion. If the film does change it will result in measurement errors with less accuracy achieved. Aerial film size is usually 23x23 cm each.

Image scanning

Photographs can be scanned into a digital format that can be imported into digital image processing software. Specialized scanners are used. These scanners preserve radiometric and geometric integrity of the scanned image.

Digital Cameras

Recently digital cameras are used, therefore the data (photograph) is already in a digital format hence there is no need for the specialized scanner.

2. Image Control

This component is important because it is the control that is used to establish the position and orientation of the camera at the moment of exposure. Photo Mosaics require no control, Rectified aerial control requires partial control; Mapping and Orthophotography requires full control information. Photographs can be controlled using three different methods:

1. Ground control points which are surveyed by normal survey methods
2. Bridging control through aerial triangulation. This is done by computing on the photographs common points that appear in three successive photographs or in two adjacent strips and computing their 3 dimensional coordinate values.

3. Aerial photography control by kinematic GPS measurements, this will give the position and elevation of the camera without the use of ground control.

2.1 Locations for ground control and selecting which type of targeting to be used There are two main types of ground control, targeted and photo identifiable control points. Targeting is an integral part of photogrammetric mapping and should be carefully considered. When targets are positioned, it should not be affected by shadows. The targets should preferably be symmetrical in shape and an adequate size. Being able to easily identify the targets on a clear image enhances the accuracy and efficiency of the photogrammetric process.

2.2 Field Surveying the control points Photogrammetric control is usually fixed by traditional survey methods. Control should be spread out widely, thus making the GPS the most effective survey method for establishing photogrammetric control.

2.3. Aerial Triangulation
This is the process of calculating the Y, X and Z of ground coordinates on specific point from measurements on a photograph. Aerial Triangulation can also be linked with bridging. Aerial Triangulation provides necessary control for the stereo model using a limited amount of surveyed control points. It also provides consistency checks for field surveyed control points.

2.4. In the future, this component could be eliminated when advanced GPS technology will be able to solve the photo orientation problem without needing ground control. Ground control is only used to recover the position and orientation of the photograph at its moment of exposure. Replacing the need for ground control reduces the number of field surveyed control points and in return minimizing time and costs in the photogrammetric process.

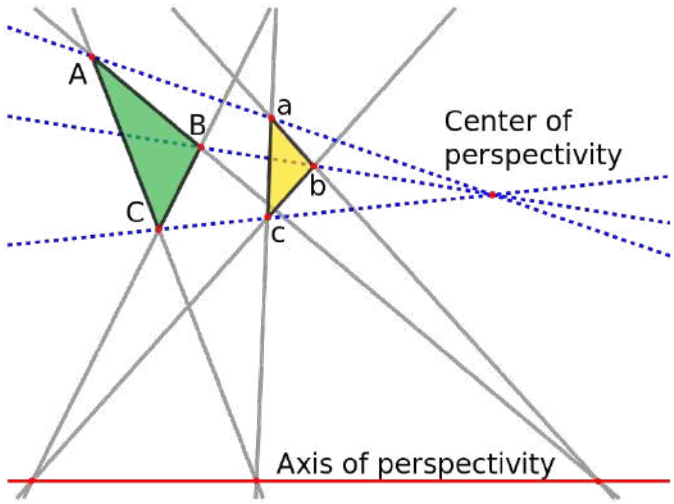
3. Product Compilation

3.1. The product compilation varies and is dependent on the nature of the final product.

3.2. Each of these components requires the utilization of different equipment, different measurement techniques, and different data processing. The most commonly used photogrammetric instrument is the stereo plotter. Its main purpose is to reconstruct the original orientation and the geometric integrity of an image at the moment of exposure and to collect three dimensional data.

Central perspective Geometry:

Two figures in a plane are **perspective from a point** *O* if the lines joining corresponding points of the figures all meet at *O*. Dually, the figures are said to be **perspective from a line** if the points of intersection of corresponding lines all lie on one line. The proper setting for this concept is in projective geometry where there will be no special cases due to parallel lines since all lines meet. Although stated here for figures in a plane, the concept is easily extended to higher dimensions.



The line which goes through the points where the figure's corresponding sides intersect is known as the **axis of perspectivity**, **perspective axis**, **homology axis**, or archaically, **perspectrix**. The figures are said to be perspective from this axis. The point at which the lines joining the corresponding vertices of the perspective figures intersect is called the **center of perspectivity**, **perspective center**, **homology center**, **pole**, or archaically **perspector**. The figures are said to be perspective from this center.

If each of the perspective figures consists of all the points on a line (a range) then transformation of the points of one range to the other is called a *central perspectivity*. An important special case occurs when the figures are triangles. Two triangles that are perspective from a point are called a *central couple* and two triangles that are perspective from a line are called an *axial couple*.

Flying Height of a Vertical photograph:

Flying height is defined as the vertical distance between the exposure station (track of aircraft) and mean sea level.

The problem of determining the flying height of a vertical photograph from one control line will be outlined for both the Church and Anderson Methods.

Problem on church method:

Given:

Point	x	y	X	Y	h
a	00.000 mm	+76.531 mm	5,000'	25,000'	400'
b	+78.947 mm	+78.947 mm	15,000'	25,000'	1,000'

Focal Length, f = 150.000 mm.
Photo Distance, P= 78.984 mm.
Ground Distance, D= 10,000'

The line, ab, was chosen so as to result in an he correction that is common to the Anderson Dropped Perpendicular Method. If the line were taken radially from the principal point there would be no he correction. Since point a lies on the +y axis and there is relatively little y difference between point a and b, the mathematical computations are made easier for the rectangular coordinate system of the Church Method.
Even though "square rooting" in this particular problem can be done visually, the four terms will be listed for they may be of any conceivable magnitude. The correct flying height for the given photographic and control data is 20,000'. Although this is the answer, it is given now to aid the reader in following the successive determinations.

= (10,000)(150.000)/ (78.984) + 400 + 1,000/2

= 19,691.2'

This is the first approximate flying height based on the photographic scale times the focal length, plus the average elevation of the control points.

First Determination :

$$X_a = \frac{H - h_a}{f} \cdot x_a \qquad Y_a = \frac{H - h_a}{f} \cdot y_a$$

$$X_b = \frac{H - h_b}{f} \cdot x_b \qquad Y_b = \frac{H - h_b}{f} \cdot y_b$$

$$X_a = \frac{(19{,}691.2 - 400)(0.000)}{150.000} \qquad Y_a = \frac{(19{,}691.2 - 400)(76.531)}{150.000}$$

$$X_a = 0.0' \qquad Y_a = 9{,}842.5'$$

$$X_b = \frac{(19{,}691.2 - 1{,}000)(78.947)}{150.000} \qquad Y_b = \frac{(19{,}691.2 - 1{,}000)(78.947)}{150.000}$$

$$X_b = 9{,}837.4' \qquad Y_b = 9{,}837.4'$$

$$D_1 = \sqrt{(9{,}837.4 - 0.0)^2 + (9{,}837.4 - 9{,}842.5)^2}$$

$$D_1 = 9{,}837.4'$$

Correct H_1 proportionally to the change required in the computed distance, where h is the average elevation of the control points:

$$\frac{D}{D_1} = \frac{H_2 - h}{H_1 - h} \qquad \text{Eq. (4C)}$$

$$\frac{10{,}000.0}{9{,}837.4} \qquad \frac{H_2 - 700}{19{,}691.2 - 700}$$

$$H_2 = 20{,}005.1$$

$$X_a = \frac{(20{,}005.1 - 400)(0.000)}{150.000} \qquad Y_a = \frac{(20{,}005.1 - 400)(76.531)}{150.000}$$

$$X_a = 0.0' \qquad Y_a = 10{,}002.7'$$

$$X_b = \frac{(20{,}005.1 - 1{,}000)(78.947)}{150.000} \qquad Y_b = \frac{(20{,}005.1 - 1{,}000)(78.947)}{150.000}$$

$$X_b = 10{,}002.6' \qquad Y_b = 10{,}002.6'$$

$$D_2 = \sqrt{(10{,}002.6 - 0.0)^2 + (10{,}002.6 - 10{,}002.7)^2}$$

$$D_2 = 10{,}002.6'$$

$$\frac{10{,}000}{10{,}002.6} = \frac{H_3 - 700}{20{,}005.1 - 700}$$

$$H_3 = 20{,}000.1'$$

Designing a Flight Route

The first step in the design is to decide on the scale of imagery or its resolution and the required accuracy. Once those two requirement are known, the following processes follow:

- planning the aerial photography (developing the flight plan);
- planning the ground controls;
- selecting software, instruments, and procedures necessary to produce the final products;
- cost estimation and delivery schedule.
- For the flight plan, the planner needs to know the following information,

some of which he or she ends up calculating:

- focal length of the camera lens;
- flying height above a stated datum or photograph scale;
- size of the CCD;
- size of CCD Array (how many pixels);
- size and shape of the area to be photographed;
- the amount of end lap and side lap;
- scale of flight map;
- ground speed of aircraft;
- other quantities as needed.

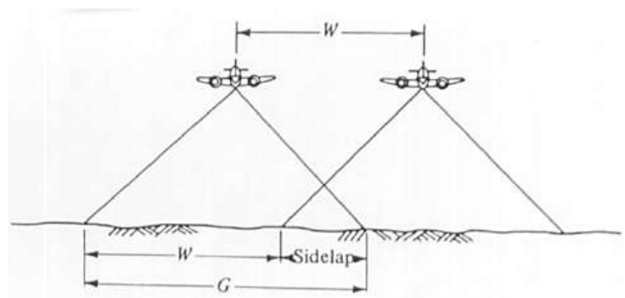
Overlaps:

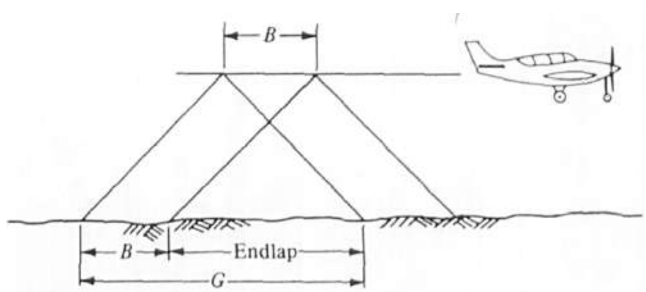
Vertical aerial photographic coverage of an area is normally takenas a series of overlapping flight strips. As illustrated in below pictures, the end lap is the overlapping of successive photos along a flight strip and the side lap is the overlap of adjacent flight strips.

If stereoscopic coverage of an area is required, the absolute min end lap is 50%. However, to prevent gaps from occurring in the stereoscopic coverage due to crab, tilt, flying height variations, and terrain variations, end laps > 50% are used. Also, if the photos are to be used for Photogrammetry control extension, images of some points must appear in three successive photographs, a condition requiring > 50% end lap.

For these reasons aerial photography for mapping purpose is normally taken with about 60% end lap + 0r – about 5%.

Side lap is required in aerial photography to prevent gaps from occurring between flight strips as a result of drift, crab, tilt, flying height variations and terrain variations. Mapping photography is normally taken with a side lap of about 30%. An advantage realized from using this large a percentage is elimination of the need to use the extreme edges of the photography, where the imagery is of poorer quality. Having distortions of image due to tilt and relief.





Adjacent flight strips are photographed so that there is also a common coverage which is called lateral overlap or side lap and is normally held from 25% to 30%. The photographs of two or more side lapping strips used to cover an area is called **block of photographs**.

Crab :
Crab is a disparity in the orientation of the camera in the aircraft with respect to the aircraft's actual travel direction. It is usually the result of side winds, which cause the aircraft's direction of heading to deviate form its actual travel direction as showed in below picture.

Drift :
Drift is the term applied to a failure of the pilot to fly along planned flight lines. It is often caused by strong winds. Excessive drifts are the most common cause for gaps in photo coverage when this occurs, reflights are necessary.

Scale of photography :

The mean scale of photography depends on the focal length of the camera and flying height as evident from the following relationship.

Aerial Photographs and Digital Orthophotographs

Aerial photographs are captured by cameras installed in (or attached to) small airplanes, helicopters, unmanned vehicles, balloons, kites, and other systems. These photos are often printed onto photo paper for use in both the office and outdoors in the natural environment. Digital orthophotographsare either single aerial photographs or photo composites that have been converted to digital form (if initially captured on film) and georeferenced using ground control points for use in GIS or GPS receivers. Digital orthophotographs are different from aerial photographs in that a large proportion of the tilt and topographic displacement of features inherent in a single aerial photograph are removed. A digital orthophotograph composite is essentially a collection of individual aerial photographs that have been stitched together and georeferenced. These are commonly used in GIS and Internet-based mapping applications such as Google Earth. Upon close examination of these images, the edges of individual aerial photographs are apparent.

TYPES OF AERIAL PHOTOGRAPHS:

Based on orientation of camera axis photographs are classified into 3 types. 1. Vertical Photographs 2. Low Oblique Photographs and 3. High Oblique Photographs

Vertical Photographs:

These are the photographs which are acquired when the axis of camera is in vertical condition. Following are some of the important points related to vertical photographs.

At a given height (flying height) these photographs cover relatively less amount of area compared to an oblique photograph.

Relief is not readily seen in a vertical photograph.

Scale is considered approximately uniform for flat terrains in case of vertical photographs.

A vertical photograph can be used as a substitute in the absence of map.

Low Oblique Photographs:

Photographs which are taken keeping the camera axis intentionally tilted are called as Oblique Photographs. If horizon is not visible in such photographs, they are categorized as low oblique photographs. Horizon is the area where earth and sky appears to be meeting in a photograph.

High Oblique Photographs:

These are oblique photographs, where horizon is visible in the photographs. These photographs are taken with high amount of tilt and cover larger area compared to vertical photographs. Scale is normally not uniform even in case of a plain terrain for oblique photographs.

Photogrammetric imaging Devices :

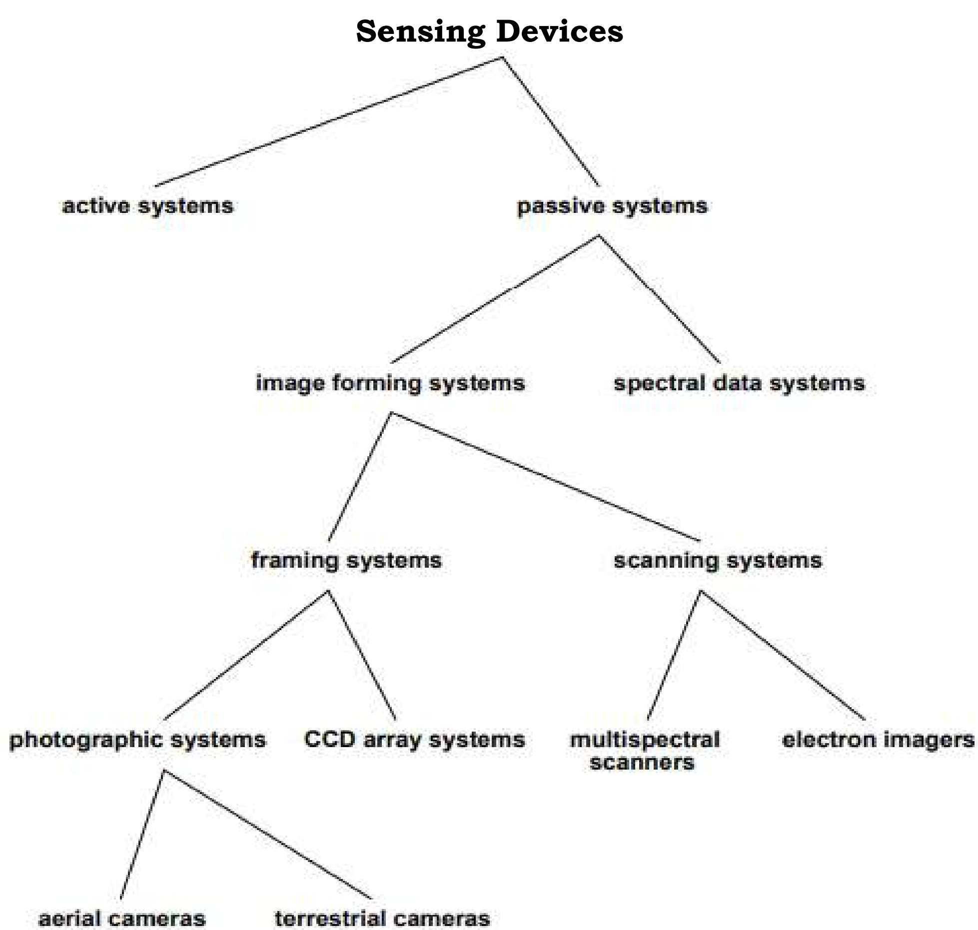


Figure 2.1: Classification of sensing devices.

Of all the sensing devices used to record data for photogrammetric applications, the photographic systems with metric properties are the most frequently employed. They are grouped into aerial cameras and terrestrial cameras. Aerial cameras are also called cartographic cameras.

Terrestrial Photogrammetry is based on stereo or multi-image restitution of a block of overlapping images: collinearity equations allow to determine the 3D model of the overlapped area. A sequence of overlapping images is acquired with calibrated digital cameras. Georeferencing and block control is obtained, depending on hardware and processing facilities:
(i) measuring a set of ground control points by total station or GPS;
(ii)determining the camera position by a GPS tied to the camera and synchronized with the image acquisition.

Main results:

High resolution 3D models (possibly geo-referenced)
Map of morphological changes
Identification and quantification of mass movements
Extraction of geometric features for structural and geo-mechanical analysis

Aerial Cameras

Aerial cameras are highly specialised instruments developed to enable accurate and consistent imagery of the earth to be obtained from an aircraft. They are referred to as "passive sensors" in that they detect and capture the natural light reflected from objects.

Early film cameras were hand-held surveillance instruments used by various armies to obtain pictures of the enemy. These rapidly developed into high altitude "fixed to the aircraft" types that held rolls of film enabling many frames of photography to be exposed in single sorties. Later developments in camera and film technology enabled infrared film to be used for specific imagery capture, but it was the advent of digital technology that enabled capture of not only the visible light spectrum but also radiation at either end of the visible light range. Digital sensors are used in many platforms including satellite, manned aircraft, unmanned aircraft, land-based vehicles and in static placements. Digital cameras have a further advantage in that their imagery pixels can be used to create point cloud elevation data sets.

Conversion of aerial photographs to Digital format :

Aerial photographs recorded with standard mapping cameras must be scanned and converted to raster format before they can be used in digital image processing/mapping environments. Decisions made concerning the scanning process will determine, in large part, the geometric accuracy of the scanned photographs, the amount of information that can be extracted and the speed with which the images can be processed.

The basic function of a scanner is to convert a hardcopy photograph to digital format (that is, softcopy format). Scanners are designed to capture image data in reflection (paper print) and/or transmission (film transparency) modes. Because film transparencies tend to have higher spatial resolutions and a greater range of gray values than paper prints, they are the preferred source material when converting aerial photographs to digital images.

Low-cost, flatbed scanners are generally designed for desktop publishing applications. They offer adequate spatial and radiometric resolution for capturing detail from large scale aerial photographs, but may introduce unwanted geometric distortions into the scanned image. Some low-cost, flatbed scanners advertise high resolution, but are actually scanning at low resolution and resampling to higher resolutions through the use of software. These types of scanners are useful for documents and graphics applications, but are not optimal for scanning aerial photographs to be used in GIS or mapping.