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BGGCT-133
GENERAL CARTOGRAPHY

Block

2

MAP PROJECTIONS

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BLOCK 2: MAP PROJECTIONS

You may create a map for small area without facing much trouble but, making a flat map for the entire globe is a difficult task. So, how do you make an accurate flat map for covering a large area? Different methods and techniques have been developed for making such maps by the cartographers across the globe through out its history. However, it is also apparent that none can exactly be able to represent the true shape of earth on map. Every method of construction of globe has its own merits. The transformation of earth's three-dimensional surface into two-dimensional plane on a map using mathematical formulae is called a map projection. This transformation process is involved in preserving the area, shape, direction and distance of a specific area. One can understand that the flattening of earth is not possible without distortion in fashion. All of these information, we generally study under the subject of mathematical cartography which deals particularly with the map scales and projections.

In this block, we will learn different types of map projections and methods for constructing graticules of the globe.

Unit 1 Introduction to Map Projections:

Map projection transforms a spherical surface to a flat surface. While flattening the earth's surface features to a map, you will find significant distortions. Some projections distort areas, form of places and also distort distances. If a projection preserves the property of area then other properties automatically distort. In order to get basic knowledge of map projections, we have introduced the concept of graticule, properties and types of projections and projection terminologies in this unit.

Unit 2 Cylindrical Projections:

The straight lines of all parallels, which are parallel to the equator and meridians, which are perpendicular to the equator, intersect each other at right angles everywhere. In this unit, the basic principle of cylindrical map projections and their properties and uses are discussed. The three types such as simple cylindrical projection, cylindrical equal area projection and Mercator's projections are explained in detail.

Unit 3 Conical Projections:

Conical projections are characteristically generated by the straight converging lines of meridians and concentric circular arcs of parallels. There are several types of conical projections, however, you will study particularly about conical projection with one and two standard parallels and Bonne's projections in this unit.

Unit 4 Zenithal Projections:

This unit introduces you about the zenithal projections which are also called azimuthal projections. One of the important properties of this type is that they show correct bearings, hence, predominantly used in navigational purposes.

We hope that after studying this block, you will be able to get an idea about the basic concepts of map projections, types of projections, properties and uses of map projections. Our best wishes are always with you in this endeavour.

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UNIT 4

INTRODUCTION TO MAP PROJECTIONS

Structure

4.1 INTRODUCTION

You have studied about the nature and scope of cartography, maps and map scales in Block-1 of this course. In this unit, you will learn about the map projections. This unit basically provides the basics of map projections and their classification according to the preservation qualities. The cartographer must have the knowledge of map projections and need to understand their characteristics so that he/she can succeed in map making and designing.

To do this, fundamental awareness of geodesy including geographical coordinates and properties of graticules have been introduced in Sections 4.2 & 4.3. The map projection is technically involved in a transformation process by which we obtain our flat two-dimensional map from the three-dimensional surface. From Section 4.4, you will learn about the classification of map projections. You will also study the important projection properties and uses and map projection terminologies from Sections 4.5 & 4.6.

Expected Learning Outcomes

After studying this unit, you should be able to:

- differentiate between the sphere and spheroid of earth's shape;
- explain the geographical coordinates of globe;
- describe the properties of graticules of the spherical globe;
- define map projection and classify map projections;
- depict the properties of projections and their uses; and
- describe the terminologies which are used in studying map projections.

4.2 GEOGRAPHICAL COORDINATES

If somebody asks you where are you living? Your response would be the name or address of your living place for example Kakinada in Andhra Pradesh state of India. Think, how many of people are fully aware of the given address globally. Some of them may know the particular place but certainly not all. So, it is very difficult to identify your location by saying the name of a town or village, etc. Then, how do you identify your place of location on the earth? You may immediately check mobile phone for GPS observation or you may search for prominent places, building structures or other things around you for explaining your whereabouts. A person's *location* may or may not be possible to identify through mobile phone number. And, places or things that are known to you may also not be able to provide accurate information of your place of location. So, in this case what do we require for identifying a location of a person, place, or thing anywhere on the globe. The answer is not very difficult. To explain the exact place of your location requires the values of latitude and longitudes. These latitude and longitudes are called geographical coordinates. Geographic coordinates can facilitate us to show every location on the surface of earth. We, geographers, design the maps for the globe by projecting the grid of geographic coordinates through systematic and scientific process. Therefore, the study of geometric relationships of the geographic grid is essential in selecting suitable map projection and other map design aspects.

A geographic coordinate system is the primary locational reference system for the earth. It uses a three dimensional (3D), spherical surface to define locations on the earth. To study geographical coordinates, you must understand the geometrical form of earth's shape. Do you think, is it necessary to study the shape of the earth? Yes, it is very important because the transformation of earth's features from 3D to 2D (two-dimension), on a piece of flat paper creates number of problems including distortions in distances and shape etc. To overcome such problems, we adopt suitable map projections for preparing a map. Now, it is important for you to study about the earth's shape.

4.2.1 Earth's Shape: Sphere and Spheroid

Initially, Ancient Greeks observed that the navigational sailing ships disappear from view hull first, mast last, rather than sudden disappearance as a smaller dot on the horizon of a flat earth. Besides that, they also noted the celestial observations particularly lunar eclipses as evidences for concluding the idea of a ***spherical earth***. One of the prominent Greek scholar Eratosthenes (about 250 B.C), tried to calculate earth's circumference based on the observation of a deep well in Syene, near present-day Aswan in southern Egypt, where the sunlight touches the bottom of the well only during the summer solstice on June 21. His assumption was that Syene is located on Tropic of Cancer (23½ degree), where the Sun remains directly overhead on solstice. Then he decided to measure the angle above the solstice horizon of the noon Sun at Alexandria which was found to be 82°48' on the next solstice. Then, the vertical lines of both locations extended to center of the earth for calculating the difference of angle between Syene and Alexandria which was noted as 7°12' (90°00'-82°48'). The angle of 7°12' would be of 360° i.e., whole earth's circumference, or 1/50th part of the circumference. He also estimated the travelling distance between two cities was 5,000 stadia which equals to 925 kilometers. Therefore, the estimated earth's circumference is 2,50,000 stadia (46,250 kms), which equals to the 1/50th part of the circumference (i.e. 50x5000 stadia). It was measured quite accurately close to the present calculations of 40,075 kms.

Until 17th century, our planet earth was assumed to be a ***sphere*** in shape. It was the year around 1670, when Isaac Newton first proposed that the earth bulges at the equator and flattens at the poles due to the centrifugal force which is generated by the earth's rotation. Because of earth's fixed axis of rotation, the direction of centrifugal force is always outward away from the axis. A rotating body tends to form an oblate spheroid rather than a sphere. He predicted the bulging, which occurs because of the unequal pull of gravity, is approximately 1/300th part of the equatorial radius. Since then, the cartographers are referring this concept of oblate ***spheroid*** or oblate ***ellipsoid*** to the earth.

Let us now understand the ***spheroid (ellipsoid),*** shape of earth. The shape of an ellipse is defined by two radii i.e., the longer radius (a: semi-major axis), and the shorter radius (b: semi-minor axis). Rotating the ellipse around the semi-minor axis creates a spheroid or ellipsoid. You may refer Figure 4.1, where *'a'* represents semi-major axis or equatorial radius and *'b'* shows semi-minor axis or polar radius. The amount of polar flattening or oblateness is the difference in length between the two axes expressed as a fraction or a decimal.

$$f = \frac{a-b}{a}$$

Flattening is expressed as *1/f.* f values vary from 0 to 1 where zero means the two axes are equal, resulting into a sphere. The flattening of the earth is approximately 0.003353 *(a=6,378,137 m and b = 6,356,752.31414 m)*. Today scientific values based on satellite orbital data are around 1/298th of the equatorial radius. You must always remember that we use sometimes a sphere for maintaining accuracy of small scale maps (1:5,000,000 or smaller), whereas, for large scale maps (1:1,000,000 or larger), a spheroid is essential to represent the shape of the earth. Usage of sphere or spheroid generally depends on the purpose of map and data accuracy. The suitable reference ellipsoids are chosen by various countries for their needs of mapping.

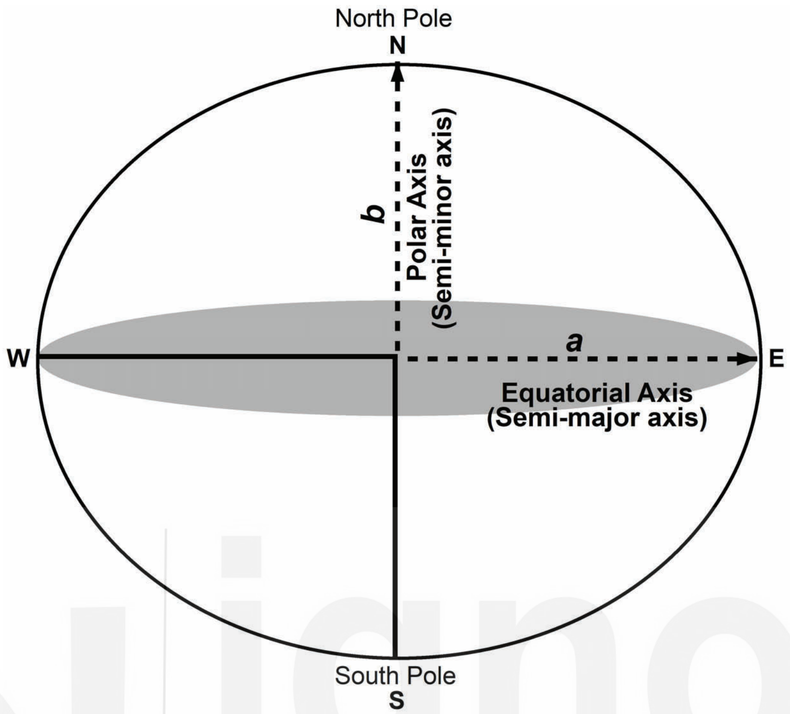


Fig. 4.1: Spherical or ellipsoidal shape of the earth.

Do you think that one particular spheroid is exactly fit for the entire world? It is not true as every spheroid is essentially fit for all regions of the world. World Geodetic System-1984 (WGS-84), ellipsoid is designed for worldwide use and is considered to be more accurate than the other ellipsoids for example, Clarke, Everest, etc. If you check any smart mobile, you may find the GPS or navigation option in it. This tool or button actually works on Global Positioning System (GPS), technology which is based on the WGS-84 ellipsoid. You also remember that the earth is neither a perfect sphere nor a perfect spheroid due to variations of gravity and the surface features.

4.2.2 Graticule: Latitude and Longitude

Now you have understood the earth's geometrical form of sphere and ellipsoid shape. Defining a particular location on the earth or any spherical body requires an angular unit of measure, a prime meridian, and a datum (based on a spheroid). Angular measurement is generally based on a **sexagesimal** scale. A circle is divided into 360 degrees and each degree into 60 minutes, and each minute into 60 seconds. This determination method is called sexagesimal scale or also referred to as Degrees, Minutes, and Seconds format or **DMS format**.

As we know that the earth rotates in an imaginary axis termed as the axis of rotation. The axis of rotation is supposed to emerge on a particular place of the earth is called geographic north or the North Pole whereas the opposite point is named as geographic south or the South Pole. If an imaginary plane passes through the sphere perpendicular to and bisecting the axis of rotation, the intersection of the plane with the earth's surface would form a complete circle. This circle bisects the earth into two halves is defined as a *great circle* or also called the ***equator***. Other than the equator, all other imaginary circles are referred to as small circles. In the geographic coordinate system, the equator, the north pole and the south poles are the most important elements.

Defining a location on a map can also be done by using a grid. An evenly spaced network of horizontal and vertical lines is called a grid. It can be made by the specified number of rows and columns by choosing the reference grid for a map. Grids are also used to display measured locations using projected coordinates on the map. Whereas, graticules are the network of horizontal and vertical lines showing parallels of latitude and meridians of longitude, respectively, for the earth. The specific use of graticules is that the location of the earth can be shown with geographic coordinates i.e. degrees of latitude and longitude (Fig. 4.2). You will study now about the latitude and longitude.

Latitude

The location of a point on the earth is referenced by its ***latitude*** and ***longitude*** values. Knowing the point of location is required to determine the latitude, the north-south angular distance from the equator, and the longitude, the east-west angular distance from the prime meridian.

It can be understood that latitude is simply the location on the earth's surface between the ***equator*** and either the North or the South Pole. The angles are measured in degrees or grads. The latitude of equator is 0 degree and 90 degrees at the poles. The line connecting all points on the same latitude is called a ***parallel***. In the spherical system, horizontal lines or east-west lines are the lines of equal latitude or *parallels*. You can imagine that every place on the earth can have a parallel. It is labeled with N or S with respect to the position north or south of the equator.

The surface distance may vary for each degree of latitude for example 110.57 km at 0° and 111.23 km at 50° on the WGS 84 elliposoid. The latitude can be expressed as 18° 45' 30" N, 18° 45' 30" S, etc., in the format of degree, minute and seconds.

Longitude

You are now well aware of specifying a location on the earth which requires the determination of latitude and longitude values. Determining the ***longitude*** is somewhat difficult than latitude, since the earth continuously rotates on its own axis. This makes it difficult to fix the point where to begin for counting the position. Hence, we require a fixed reference point. We know that the earth approximately takes 24 hours time to move 360 angular degrees in a day or 15 degrees in each hour. If anybody concentrates to determine the difference in time between the local time and the fixed point of reference, this could be converted into angular degrees and hence position. After several international discussions and agreements, the line passing through the British Royal Observatory at Greenwich, near London, in England was designated as the origin for longitude. The line is also called as the ***prime meridian*** or 0°

longitude. It was agreed at the International Meridian Conference held at Washington DC, in 1884. A meridian of longitude is defined as all points on the earth having the same longitude which form a line from pole to pole. The selection of the prime meridian may be of national or international importance, not same as the latitude-equator which is the natural starting place. Opposite to the prime meridian, the line of 180° meridian in the Pacific Ocean is drawn which provides a convenient place for the International Date Time.

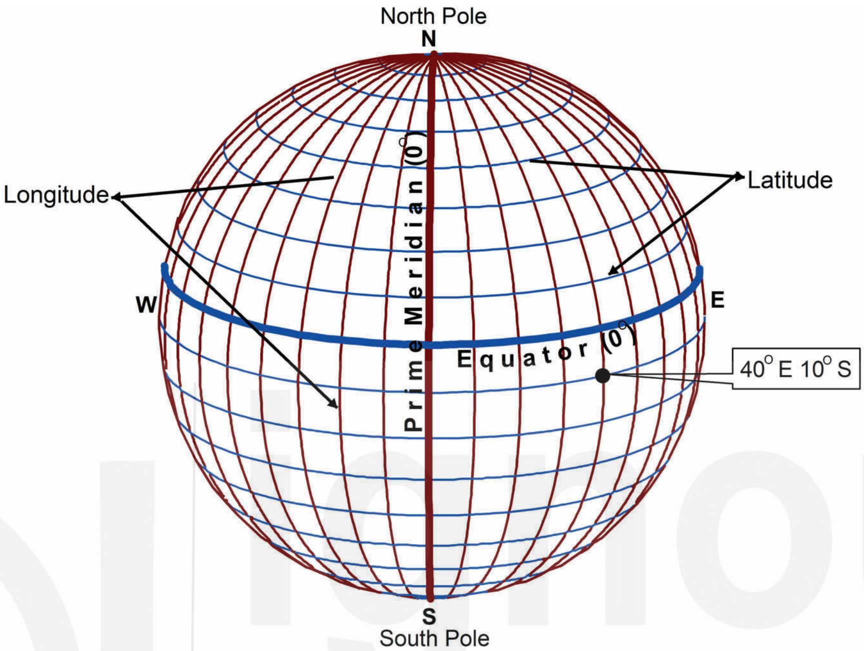


Fig. 4.2: Globe showing latitudes (blue lines) and longitudes (red lines).

Longitude can be thought of as the angle formed by a line going from the intersection of the prime meridian and the equator to the centre of the earth, and then back to intersection of the equator and the local meridian passing through the position. It ranges from 180° W to 180° E of the prime meridian and converging toward the poles. Longitude position is designated as 0° to 180° east or west of the prime meridian for a total of 360°. Based on WGS 84 ellipsoid, the length of one degree of longitude at the equator or 0° is 111.32 km and the length is 0 km, 19.39 km, and 71.7 km corresponding to 90°, 80°, 50°, respectively. The length of longitude gradually narrows starting from the equator, until all the meridians converge at the poles. It may be referred to as ***convergence of meridians*** (or meridional convergence). Therefore, vertical lines or north-south lines are lines of equal longitude or meridians. You must always remember that the north and south are marked to the latitudes above and below of the equator whereas the west and east are designated to the longitudes left and right of the prime meridian.

SAQ 1

a) Who discovered the earth's bulging at the equator?

b) How did Eratosthenes estimate the earth's circumference?

c) What is prime meridian? Explain.

4.3 PROPERTIES OF GRATICULES

You have understood the basic principles of graticules. However, you also need to study further about their role in constructing a globe. As you know that the parallels and meridians are the lines that encompass the globe and form a gridded network called a graticule. The origin of graticule (0,0), is defined by where the equator and prime meridian intersect each other. The important properties of graticules are described here assuming the earth as sphere.

- The equatorial circumference does not equal the meridional circumference because of flattening at the poles.
- The length of the degree along the meridian is not constant and the meridian is equal to one-half the circumference or half the length of the equator.
- No parallel in one hemisphere is equal in length to any other in the same hemisphere.
- The spacing between meridians is equal along a given parallel.
- The space between meridians decrease towards poles and all parallels decrease in length at higher latitudes.
- All meridians converge toward the north and south poles and diverge toward the equator. The poles are points.
- Meridians and parallels intersect at right angles.
- The azimuth as an angle is counted clockwise from geographic north through 360 degrees and the angular measure is followed by either N or S.
- The equator is the great circle and other parallels of latitude are small circles. All great circles have equal lengths; all meridians are of equal length and are equal to the equator.
- Scale is the same everywhere on the globe.

SAQ 2

Define a graticule.

4.4 CLASSIFICATION OF MAP PROJECTIONS

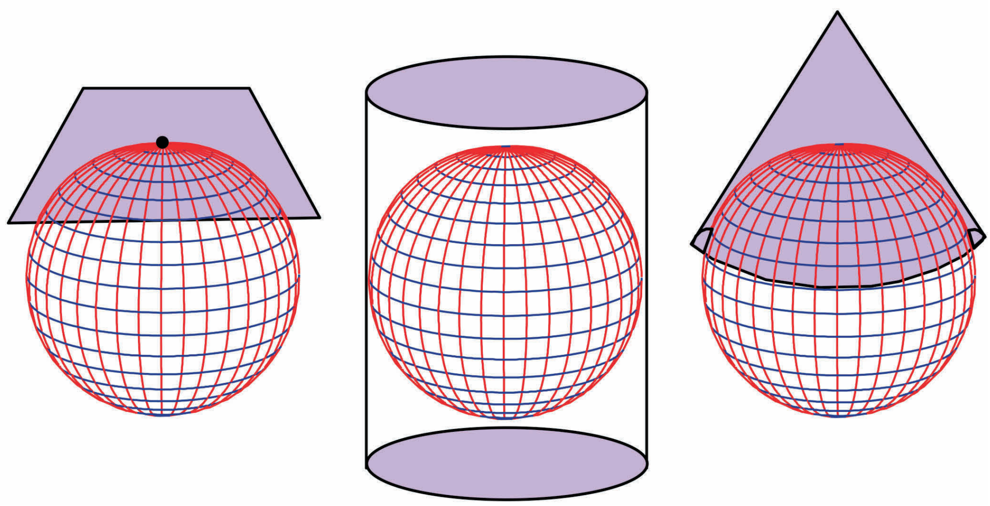
As you have already studied in the previous Block, maps have a number of features and advantages. They have specific capabilities to solve scientific and commercial problems like navigation, urban landuse, forest, infrastructure facilities etc., because the positions of locational features on maps are generally determined based on mathematical geometries. Whether you treat the earth as a sphere or spheroid (ellipsoid), you should transform its three-dimensional surface to create two-dimentional flat map by using mathematical equations which is commonly referred to as ***map projection***. To minimize any distortions or deformations which occur due to contraction and stretching of the shapes and sizes of the world’s features, map projections are essentially be used. Map scales and their variation, map numbering system and division of sheets, and map projections are particularly dealt under the subject of mathematical cartography.

We must understand that the size and location of an area on the globe can decide the type of projection which is to be adopted for it. And the purpose of map also plays an important role for selecting a map projection. In simple words, map projection can be defined as the representation of three-dimensional surface of the earth into two dimensional surface i.e. flat plane. This transformation process may be involved in preserving the area, shape, direction and distance of a specific area.

You will get to know the conventional approach which is used for classifying map projections by the cartographers. While going through the following sub-sections, you will also understand that there are several similarities and common elements among the map projections.

You may understand better about the projections by doing the following activity. You just take a transparent globe and wrap a paper around it. Imagine that the globe has graticule which means the lines of latitude and longitude. If you emanate light from the center of the globe, it will cast shadows of the graticule on the paper. Now, unwrap the paper and observe it. The graticule's shape on the flat paper is different than on the globe. You can find some distortions in terms of its shape, area, distance or direction. These distortions we can reduce with the help of a projection.

If you want to derive a map projection on a cone, we have to wrap a cone around a globe. Based on the source of light, we will get shadows of graticules on inner surface of the cone. If you cut the cone and lay it flat, you will get a projection in a working position. The cylindrical projections can also be derived in the same manner. If a plane touches the globe at a particular point, it will produce a projection called zenithal projection. The method of deriving projection from developable surfaces is presented in Figure 4.3. A number of map projections can be developed by using projection surface. But they generally fall into the following four basic categories i.e. planar, cylindrical, conical and mathematical.



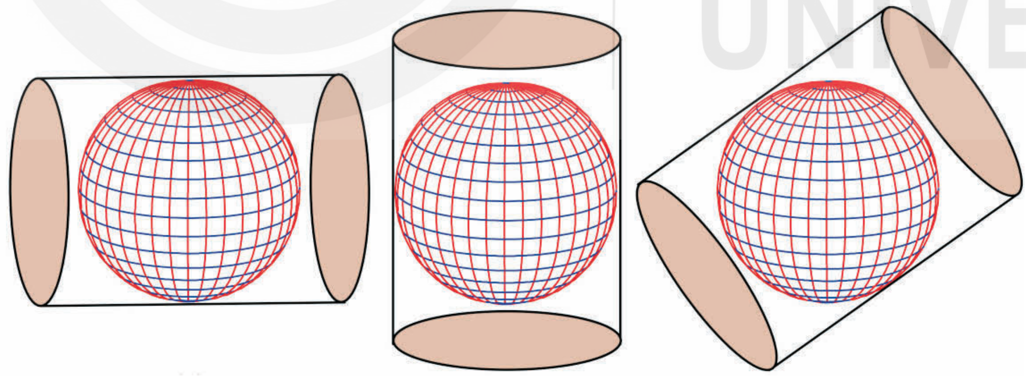
(a) (b) (c)

Fig. 4.3: Developable projection surfaces a) plane b) cylinder and c) cone.

4.4.1. Cylindrical Projections

In cylindrical projections, the equator is usually considered its line of tangency. When a point or line of the projection surface touches the earth's ellipsoidal surface, it is to be treated as tangent case and in the secant case, the two points or lines are in contact with the ellipsoid. The cylindrical projections can be developed by wrapping a flat plane into a cylinder and making it tangent along a line or intersecting two lines on the sphere. Points on the spherical grid can be transferred to this cylinder, which is then unfolded into a flat surface. It produces rectangular shape to the globe in which the meridians and parallels are represented as straight lines. These lines are intersected with each other at 90° angle. The meridians are equally spaced, while the spacing between parallel lines of latitude increases toward the poles. There are three common aspects of cylindrical projection namely normal, transverse and oblique cases observed in Figure 4.4.

In the normal aspect, the equator is the standard parallel in the case of tangent whereas in the secant case, the two standard parallels are located in the north and south of the equator. First one is great circle and the later are small circles. The least distortion can be found where the areas are parallel to the standard parallel(s), and the distortion progressively increases towards the poles. When the cylinder is rotated, the tangent and secant lines are also changed. In the transverse case, the axis of the cylinder is turned parallel to the equator where you can find the standard parallel would be a standard meridian. On the other hand, two standard lines are produced by the small circles in the secant case. It will help in preserving the scale deformation and directions. In the oblique aspect, cylinders are rotated around a great circle line located anywhere between the equator and the meridians. We must observe that scale distortion increases as we move away from any standard lines.



(a) (b) (c)

Fig. 4.4: Various aspects of cylindrical projections a) transverse b) normal and c) oblique.

You will be studying about cylindrical projections in detail in the next Unit-5.

4.4.2 Conical Projections

In the normal aspect of conical projections, the axis of the cone coincides with the axis of the sphere. It produces the straight converging lines for meridians and concentric circular arcs for parallels. No distortion can be found along the selected standard parallel in the tangent case whereas in secant case distortion can further be reduced as cone intersects the globe along two parallels. Conical projections can also have tangent and secant cases as like that of cylindrical projections (Fig. 4.5).

You will be studying more about conical projections in Unit 6.

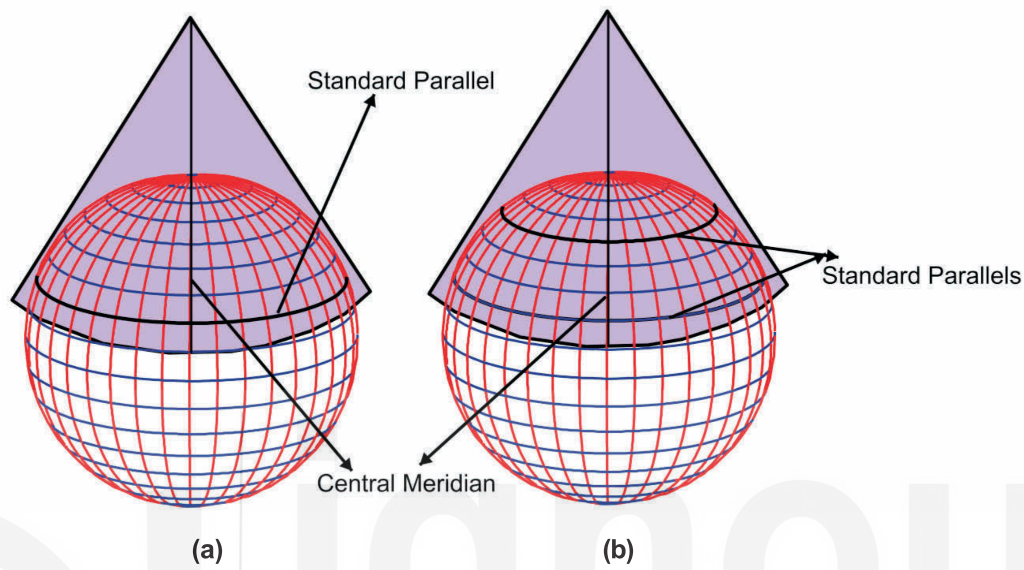


Fig. 4.5: Conical projections representing standard parallels.

4.4.3 Planar Projections

Planar projections are also called as azimuthal or zenithal projections. In these projections, the spherical grid is projected onto a plane. This plane is usually tangential to the sphere at a standard point, or pass through the sphere making a small circle line in the case of secant. The point of contact may be the poles, or on the equator, or any point on the sphere between the poles and the equator. This standard point is referred to the focus of the projection which can be identified with a central longitude and central latitude. Deformation increases with distance from either the standard point (tangent case), or the standard line (secant case).

When the plane touches the globe at the poles, the projection is known as Polar Zenithal; when it is tangent at the equator, it is called as Normal or Equatorial Zenithal; and when it touches at any other point, it is termed as Oblique Zenithal. Adjustment of light in various positions is presented in Figure 4.6.

In case the light emanates from center of the globe, the projection is referred to as Gnomonic or Central Projection. If the light source is at the point opposite to the point of tangency (or antipode position), the projection is Stereographic; when it is situated at a theoretical infinity (outside the generating globe, producing parallel light rays), an Orthographic projection is formed. For more details and the eloborate discussion, you need to study Unit-7 of this block.

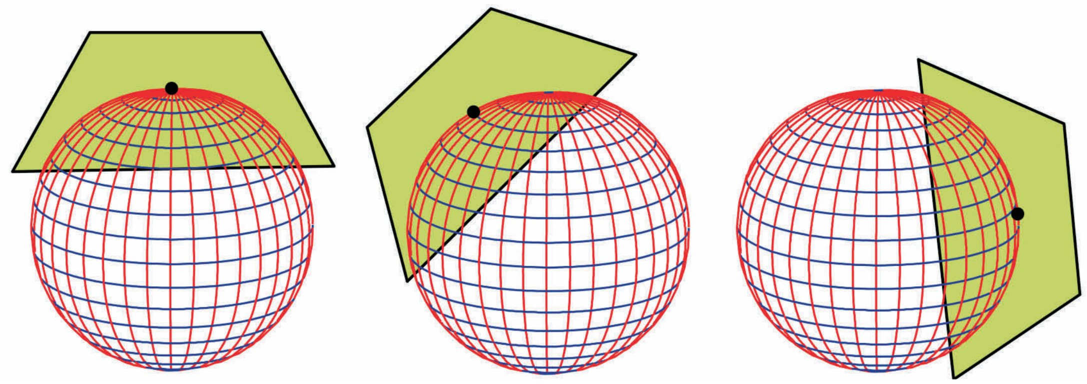


Fig. 4.6: Planar projections a) polar b) oblique and c) equatorial aspects.

4.4.4 Mathematical Projections

The above three classified projection groups such as cylinder, cone or plane are produced conceptually by projective geometry. Many projections are not related as easily to a plane, cylinder, or cone that may be placed under mathematical group of projections. These are altered versions of modified projections termed as pseudocylindrical, pseudoconic, and pseudoazimuthal. Pseudocylindrical projections are perhaps the most common type in the mathematical projections, with their meridians that curve toward the poles. To reduce the distortion, the necessary modifications are suggested for generating mathematical projections by including additional standard lines or changing the distortion pattern.

SAQ 3

a) What is map projection?

b) What are the developable projection surfaces?

4.5 PROJECTION'S PROPERTIES AND USES

All of you are well aware that maps are flattened. Some transformations including geometrical or mathematical are made onto geometric shapes that can be flattened without stretching their surfaces. These are called developable surfaces for example cylinder, cone and plane. However, in the transformation process from the three-dimensional surface to two-dimensional plane, some distortions or errors occurs that cannot be completely eliminated. The distortion errors mainly occur due to tearing, shearing or compression of the spherical surface of the globe. The task of cartographer is to select the most appropriate projection to reduce the error while making a map.

Each projection has its own properties and is made for specific purpose. Scale plays an important role in studying these distortion errors. Different projections are used for making large scale maps, which cover small area with great details; and small scale maps, which represent the larger area.

In large scale mapping, distortion is not a significant map design problem. As the mapped area covers the country level or continental level, distortion must be a considerable problem. In such situations, the alterations of area, shape, distance and directions are to be considered to produce the error free map designs. These are generally called map projection's properties.

You must understand that no geometrical or mathematically derived projections can maintain all of these properties simultaneously. Only globe can maintain all of four properties i.e. area, shape, distance and direction. Keeping this in view, map projections are classified according to the quality they preserve as mentioned below:

4.5.1 Equal Area or Equivalent Projections

These projections are supposed to maintain the area relationships of the globe. This group of projections is designed in such a way that the meridians and parallels should not intersect at 90° angle or right angles. These projections mostly preserve the area of displayed features but not shape, direction and scale, which may be distorted. Linear or distance distortion often occurs in these projections. Equal area projections are generally used for thematic mapping at small scales. For instance, population density maps at global scale, etc., where the enumeration areas are part of the data.

4.5.2 Conformal or Orthomorphic Projections

This group of projections preserves the shapes of small areas but not for larger areas like continents. The quality of conformality is that it preserves the angles around points, and the scale remains the same in all directions about a point. On conformal projections, meridians intersect parallels at 90° angles on the map. Significant distortion can be observed at smaller scales covering large areas. You must always remember that any projection cannot maintain both equivalency and conformality properties.

4.5.3 Equidistant Projections

The important quality of equidistant projections is that the distances between certain points are well preserved. Equidistant is true from one to all other points, or from a few points to others. You must remember none of equidistance projection is true from all points to all other points. Scale is not uniform throughout the map. However, scale is maintained correctly at which the length of line on a map is of the same length as like same line on the globe, regardless of whether it is a great or small circle or straight or curved line. Hence, scale will be uniform along the lines whose distances are true. These projections are sometimes used in producing general purpose maps in atlases because such projections are neither conformal nor equal area. In these maps, the landmasses appear with minimum distortion.

4.5.4 Azimuthal or True-Direction Projections

These projections are designed to show true directions from one central point to all other points. The shortest route between two points on earth's surface is along the spherical equivalent of a straight line on a flat surface. That is the great circle on which the two points lie. These great circle arcs represent the directions of all points on the map which are accurate with respect to the center. The quality of azimuthality can also be held true with respect to the elements of equivalency, conformality and equidistance.

SAQ 4

What are the four important properties of projections?

4.6 PROJECTION TERMINOLOGIES

There are several terminologies used in the construction of map projections. Keeping in view the present scope of this Unit, some of the important terminologies are discussed.

Latitude and Longitude

Latitude is a parallel line and longitude is a vertical line. The latitude means the angular distance from the center of earth either north or south of the equator. Longitudes are lines connecting north and south poles and divide the latitudes at right angles. Latitude and longitudes are generally represented by small letters of the Greek alphabet λ (lambda), and ϕ (phi), respectively. And θ (theta), represents angle in two-dimentional polar coordinates system.

Geographic Grid

The network of horizontal lines or parallels and vertical lines or meridians constructed perpendicular to each other is referred to as geographic grid. These lines are also called the geographical coordinates. One series of lines runs from east to west and the other follows from north to south.

Plane of Map Projection

The surface of map projection is also termed as the plane of a map projection. We can find three developable surfaces or two-dimensional geometric planes namely the cylinder, the cone and the plane, and their corresponding projections are called *cylindrical*, *conical* and *planar*.

Tangent and Secants

The line or point of contact between the earth's surface and the plane of map projection is called *tangent.* If the contact is along the two lines it is referred to as *secant.* Both tangents and secants represent locations on the map projection where there is no distortion of shape, area, distance, direction or scale. However, the distortion increases while moving away from these tangent and secant cases. Map projections can be classified based on their point(s), of contact (tangent or secant), with the reference surface of the earth and their orientation (aspect).

Perspective Projections

"*As we have seen*" the projections may be termed as perspective projections. These are drawn with the help of light source. Perspective projections are derived by projecting the image of the network of meridians and parallels of a globe on any developable surface. Developable surfaces are cone, cylinder or plane.

Non-perspective Projections

All non-perspective projections are non-developable projections because they can never be transferred by light source by casting shadows of graticule capable of being flattened. These projections are produced by using mathematical formulae to satisfy certain objectives.

Loxodrome or Constant Azimuth

Loxodrome or rhumbline is a line intersecting each meridian at the same angle. It has a constant compass bearing. The equator, all meridians, and all parallels are loxodromes. All other loxodromes too cross meridians at the same angels but tend to spiral toward the pole. The loxodrome plays an important role in sailing because sailors follow the same heading throughout the journey. Only along a meridian or the equator, direction remains constant.

Great Circle Arc

A line may be drawn from center of the globe that divides sphere into two halves is called the great circle or the equator of zero degree latitude. Other than great circle, all latitudes are small circles. The great circle arcs are the shortest routes between points on the earth. Hence, navigators usually approximate a great circle arc by subdividing it into a series of constant azimuths in order to reduce the change in route during the travel.

Standard Parallel

Lines of true scale are often referred to as standard parallel. In general, distortion increases with the distance from the point of contact.

4.7 SUMMARY

In this unit, you have studied so far:

- The shape of a geographic coordinate system's surface is defined by a sphere or spheroid.
- Latitudes or parallels are arranged in north-south position and longitudes or meridians are arranged in east-west position. All points on the earth having the same latitude form a parallel and the line connecting all points on the same longitude is called a meridian line.
- The representation of parallels and meridians on map is called graticule. A simple to complex mathematical formulae is required to understand the development of a large range of projections within a framework of different cartographic methodologies.
- A map projection systematically projects locations from the surface of a spheroid (3D), to representative positions on a flat surface (2D) using mathematical transformation.
- The map projections are classified into four categories namely planar, cylindrical, conic and mathematical projections. The equidistant projections have uniformity of scale along meridians and the equator; if the area on the map of any object equals its area on the globe is called equal-area projections; and conformal projections have the quality to preserve angles and local shapes from the globe to the map.
- You have also learned some important terminologies generally used in the study of map projections.

Further, you will study in detail about the three main group of projections namely cylindrical, conical and zenithal in the next Units 5, 6, and 7 of this Block 2.

4.8 TERMINAL QUESTIONS

1. Is earth a perfect sphere? Explain.
2. Differentiate between cylindrical and conical projections.
3. Describe any six number of terminologies used in map projections.

4.9 ANSWERS

Self-Assessment Questions

1. a) Isaac Newton.
   b) Based on the observations of Sun's angle during summer solstice at Syene and Alexandria.
   c) Zero degree longitude is called a prime meridian.
2. Vertical and horizontal network of the globe.
3. a) Representation of three dimansional surface of earth into two dimensional surface with the help of mathematical formula.
   b) Developable surfaces: plane, cylinder and cone.
4. Area, shape, distance and direction.

Terminal Questions

1. The earth is an irregularly shaped spheroid. You may refer to the Sub-Section 4.2.1 for more details.
2. Your answer must include key differences between cylindrical and conical projections. Refer to the Section 4.4.
3. List out the important projection terminologies like latitude, longitude, geographic grid plane, tangent, secant, perspective projections etc. For detailed description, you may refer to the Section 4.6.

4.10 REFERENCES/SUGGESTED FURTHER READING

- Misra, R.P. and Ramesh, A. (1986). *Fundamentals of Cartography*. New Delhi: McMillan.
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UNIT 5

CYLINDRICAL PROJECTIONS

Structure

5.1 INTRODUCTION

In the previous units, we have discussed about definition of map projection in which we mentioned about the network of parallels and meridians which is called graticule. You might have also understood how this network facilitates in drawing of the maps. In other words, we can say that drawing of graticules on a flat surface is called projection. There are number of methods which have been devised to project the parallels of latitude and the meridians of longitude on a flat surface. In the previous unit, we have also discussed classifications of map projection on various bases. Two techniques which are mostly used in the drawing of projection are perspective (graphical), and non-perspective (mathematical). In perspective or graphical method, the graticule of latitudes and longitudes is projected through the source of light. Projections prepared through this technique are known as perspective projections. They are broadly grouped into three categories namely cylindrical, conical and zenithal.

In this unit, we will discuss cylindrical map projections and their common properties, uses and limitations in Section 5.2. In the following Sections i.e. 5.3, 5.4 and 5.5, we have discussed three widely used cylindrical map projections namely simple cylindrical, cylindrical equal area and Mercators' projection. Under each projection, we will describe their characteristics, uses, limitations and methods of construction. In the following two units i.e. Unit 6 and Unit 7, we will discuss about conical and zenithal projections, respectively.

Expected Learning Outcomes

After studying this unit, you should be able to:

- choose the appropriate cylindrical map projections according to their uses;
- recognize the different cylindrical map projections with the help of patterns of latitudes and longitudes;
- enumerate the characteristics of each cylindrical map projection on the basis of graticule patterns formed by the parallels of latitude and meridians of longitudes; and
- explain the function and use of the various types of map projections.

5.2 CYLINDRICAL PROJECTION

In a cylindrical map projection, it is assumed that the globe is surrounded by a hollow cylinder and the cylinder touches the globe along the equator. When the cylinder touches the globe along the equator, the axis of the cylinder coincides with the axis of the globe (Fig. 5.1). The parallels and meridians are transferred from the globe to the inner surface of the cylinder by applying certain methods. The cylinder is then cut vertically and unrolled into a flat rectangular sheet of paper and the projection is completed.

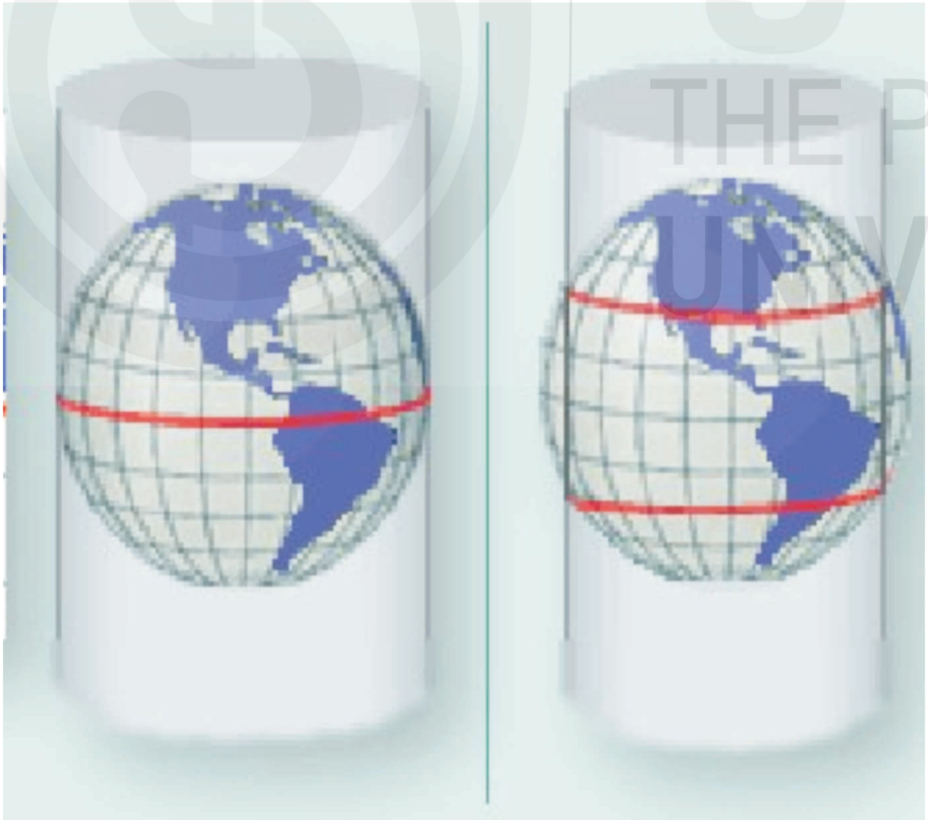


Fig. 5.1: Cylindrical projection with tangent and secant cylinders.
(*Source*: US Geological Survey, National Atlas public domain. http://www.nationalatlas.gov/articles/mapping/a_projections.html)

5.2.1 Properties Common to Cylindrical Projection

As already mentioned, the drawing of cylindrical projections is based on the principle that a cylinder whose radius is equal to the radius of the globe, surrounds the globe and touches it at the equator. Consequently, there are some properties which are common to all the cylindrical projections described as under:

i) **Shape of Parallels:** All parallels in all the cylindrical projections are drawn as straight lines which are parallel and equal in length to the equator.

ii) **Shape of Meridians:** Meridians are also drawn as straight lines which are perpendicular to the equator. All the meridians are parallel to the prime meridian and parallel to one another. They are placed at equal distances.

iii) **Intersection of Parallels and Meridians:** On the globe, the parallels and meridians intersect each other at right angles everywhere.

iv) **Scale along Parallels:** As mentioned above, the cylindrical projections are constructed on the assumption that the cylinder surrounds the globe at the equator and the radius of the cylinder is equal to the radius of the globe. Therefore, the circumference of the cylinder will be equal to that of globe. Hence, the scale along the equator on all the cylindrical projections is correct.

   The length of all the parallel is equal to the length of the equator on these projections while on the globe, their length decreases gradually as we move away from the equator towards the poles. Therefore, the scale along parallels is exaggerated away from the equator. For example, the exaggeration of the parallel scale is 1.15, 2.00, 4.00 and 5.76 times at latitudes 30°, 60°, 75° and 80°, respectively. The exaggeration of the parallel scale at the poles is infinite because the pole on the globe is only a point and it has been stretched to the length of the equator on cylindrical projections.

v) **Scale along Meridians:** Although, all the meridians on a cylindrical projections have equal length, their scale on the projection is kept correct, reduced or exaggerated depending upon the purpose of the projection. For example, meridian scale is kept correct in Simple Cylindrical Projection, reduced in Cylindrical Equal Area Projection and exaggerated in Mercator's Projection. We will discuss about these in detail in the subsequent sections where we will take up the above mentioned three projections separately.

vi) **Shape of Projection:** Since all the cylindrical projections are developed from a cylinder which is supposed to surround the globe along the equator, all the cylindrical projections are rectangular in shape.

5.2.2 Uses and Limitations of Cylindrical Projection

Cylindrical projections are best suited for the tropical zone lying between 30°N and 30°S latitudes. To be precise, it is more suited for a narrow belt along the equator. This is because of the fact that the scale along parallels and the meridians is more or less correct in this zone. Hence, the homolographic and orthomorphic properties are well preserved in these areas.

Now you might have understood that these projections are not much suited to temperate and polar areas because the scale along parallels and meridians changes drastically in these areas. This results in large scale deformity in area and shape.

5.2.3 Types of Cylindrical Projection

A number of cylindrical projections have been developed for example Simple Cylindrical Projection, Cylindrical Equal Area Projection, Gall's Equal Area Projection, Mercator's Projection and Transverse Mercator's Projection.

However, in this unit, we shall discuss only the following three types of cylindrical projections: 1. Simple Cylindrical Projection; 2. Cylindrical Equal Area Projection; and 3. Mercator's Projection.

SAQ 1

a) What is the limitation of cylindrical projection?

b) Name any three types of cylindrical projection.

5.3 SIMPLE CYLINDRICAL PROJECTION

As its name indicates, it is a very simple map projection and it is very easy to construct and understand this projection. It is also known as ***Plate Carree's* Projection** because it was invented by Plate Carree. The distance between successive parallels remains equal and it is called Cylindrical Equidistance Projection. If the interval of parallels and meridians is the same, then this projection forms a series of squares. If, however, they are different, then they will form a series of rectangles and not squares. Interval of parallels and meridians is different than the parallels and meridians will form a series of rectangles. While constructing this projection, care is taken to keep the distance between successive parallels according to the distances on the globe. In other words, the scale along meridians is kept correct.

5.3.1 Properties of Simple Cylindrical Projection

Following are the main properties of this projection:

i) Shape of Parallels and Meridians: The equator and all other parallels of latitude are drawn as straight lines. They are all parallel to the equator as well as parallel to one another. As far as meridians are concerned, the central meridian as well as all other meridians are drawn as straight lines. They are all parallel to one another and are equal to half the length of the equator.

ii) Intersection of Parallels and Meridians: The parallels and meridians intersect each other at right angles in all parts of the projection.

iii) Scale along Parallels and Meridians: As far as parallels are concerned scale along equator is correct but is exaggerated along all other parallels. The exaggeration of scale is 1.15 at 30°, 2.00 at 60° and 5.76 at 80° latitudes. At the poles, the exaggeration of the parallel scale is infinite. The exaggeration of the parallel scale is due to the fact that their length on the globe decreases as we move from equator towards the poles, till it becomes zero at the poles. However, they are as long as equator on this projection.

In the case of meridians, the scale along all meridians is correct because their length on the globe as well as on the projection is the same. Due to the correctness of the scale along the meridians, all the parallels are placed at equal distances, as a result of which, it is also known as 'Equidistant Projection'.

iv) **Special Property:** Scale along the equator is correct and it is exaggerated along all other parallels. But the scale along all the meridians is correct. Therefore, this is neither an equal area projection nor an orthomorphic projection. However, it preserves both these qualities to a reasonable degree near the equator.

5.3.2 Uses and Limitations of Simple Cylindrical Projection

Although, it is neither an equal area nor an orthomorphic projection; it provides a good combination of both the qualities near the equator. Therefore, it is useful for general purpose maps of the tropical areas. Since the scale along all the meridians is correct and the scale along the equator is also correct, a narrow strip of land running in north south direction and crossing the equator is shown with fair degree of correctness on this projection. For example, railway line connecting Cairo with Cape Town can be conveniently shown on this projection because this railway line runs in north-south direction, more or less along the 30º E longitude. The international boundary line between Argentina and Chile in South America can also be shown on this projection in a similar way because it runs in north-south direction.

This projection is suitable for showing areas near the equator only. In higher latitudes, both area and shape are distorted and this projection is suitable for temperate and polar areas.

5.3.3 Example along with Calculation and Steps for Construction

Let us discuss methods of construction of Simple Cylindrical Projection by explaining one example. You will be provided with various practical exercises which will be discussed in detail in Practical Manual.

Example 1: Draw the map of the world on Simple Cylindrical Projection on 1:250,000,000 scale at the interval of 30°.

Construction

Radius (R) of the reduced earth $\frac{250,000,000}{250,000,000}$ = 1inch (Radius of the actual earth is 250,000,000 inch)

Length of Equator $2\pi R$ or $\frac{2x22x1}{7}$ = 6.3 inches.

Interval along the Equator $\frac{6.3 \times 30^{\circ}}{360^{\circ}}$ = 0.52 inch

Steps involved in the Construction

1. Draw a circle of 1 inch radius;
2. Mark the angles of 30º, 60º, 90º, 120º, 150º and 180º for both, northern and southern hemispheres;
3. Draw a horizontal straight line of 6.3" long to represent the equator on this projection.
4. Divide this line into 12 equal parts with the help of a pair of compasses so that each part is 0.52" long. Draw a perpendicular (North-South) on West-East at the central part. This will represent the central meridian.
5. Divide the central meridian NS into six equal parts, with the help of a pair of compasses, each part being 0.52" long; in such a way that three parts are in the north of equator and the remaining three are to the south of equator. Draw lines parallel to the equator through these points. These lines will represent parallels of 30°, 60°and 90° north and south of the equator.
6. Similarly, draw lines parallel to NS and perpendicular to WE through the points already marked on WE. These lines will represent meridians of 30°, 60°, 90°,120°, 150° and 180° east and west longitudes. This will complete the network of this projection (Fig. 5.2).

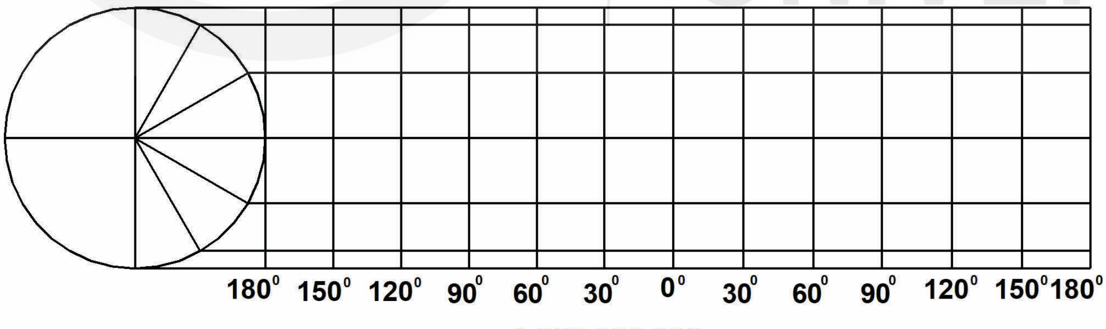


Fig. 5.2: Simple cylindrical projection.

SAQ 2

Fill in the blanks with suitable words.

a) In simple cylindrical projection, scale along _________is correct as far as parallels are concerned whereas in the case of meridians, the scale along ___________ is correct.

b) Simple cylindrical projection is useful for ______________ of the tropical areas.

c) Simple cylindrical projection is neither an_____________ nor an _______________ projection.

5.4 CYLINDRICAL EQUAL-AREA PROJECTION

This projection is also known as **Lambert's Cylindrical Projection** in which the distance between latitude decreases towards the higher latitudes. In this projection, the pole is shown with the parallel equal to the equator; hence the shape of the area gets highly distorted at the higher latitudes. Therefore, the projection is non-orthomorphic. The parallels of latitude and the meridians of longitude intersect each other at the right angle. Area lying between 45º N and S latitudes can be suitably shown on this projection. The projection is also suitable to show the distribution of tropical crops such as coffee, rice and rubber etc.

5.4.1 Properties of Cylindrical Equal-Area Projection

Properties of cylindrical equal area projection are more or less similar to simple cylindrical projection. Following are the main properties of this projection:

i) **Shape of Parallels and Meridians:** Parallels are represented by a set of parallel straight lines and are of same length as like that of the equator. Parallels are variably spaced on the meridians. Inter-parallel spacing decreases rapidly toward the pole.The tangential scale rapidly increases pole-ward and is infinity at the poles.

Meridians are parallel straight lines truly spaced on the equator. Meridians are of same length equal to the diameter of the globe.The inter-meridian spacing is uniform on all the parallels.The pole is represented by a straight line equal to the length of $2\pi R$.

ii) **Intersection of Parallels and Meridians:** Like other cylindrical projections, the parallels and meridians intersect each other at right angles in all parts of the projection.

iii) **Scale along Parallels and Meridians:** The scale along the standard parallel i.e., the equator is true. Along other parallel and all meridians, scale is not true.

The amount of exaggeration in scales increases in both parallels and meridians as we move from the equator towards the pole. The exaggerations in scales are so much that it leads to distortion of shape in the political map of the countries located in the sub-polar and polar areas.

5.4.2 Uses and Limitations of Cylindrical Equal-Area Projection

- This projection is most suitable for the area lying between 45º N and S latitudes.

- It is most appropriate to show the distribution of tropical crops like rice, tea, coffee, rubber and sugarcane etc..
- Distortion increases as we move towards the pole.
- The projection is non-orthomorphic.
- Equality of area is maintained at the cost of distortion in shape.

5.4.3 Example along with Calculation and Steps for Construction

Let us try to understand the procedure followed for calculating the radius of the reduced earth (R), and steps involved in the construction of Cylindrical Equal-Area projection by solving the below given example.

Example 2: Draw a Cylindrical Equal-Area Projection for the world map on the scale of 1:320,000,000 with the interval of 15º.

In drawing the projection, the following steps are followed.

Calculation

Radius (R) of the reduced earth $\frac{640,000,000}{320,000,000}$ = 2 cm (Radius of the actual earth is 640,000,000 cm)

Length of Equator $2\pi R$ or $\frac{2x22x2}{7}$ = 12.57 cm

Interval along the Equator $\frac{12.57 \times 15^{\circ}}{360^{\circ}}$ = 0.52 cm

Steps involved in the Construction

1. Draw a circle of 2.0 cm radius.
2. Mark the angles of 15º, 30º, 45º, 60º, 75º and 90º for both, northern and southern hemispheres.
3. Draw a horizontal straight line of 12.57 cm long to represent the equator on this projection.
4. Divide this line into 12 equal parts with the help of compass so that each part is 0.52 cm long. Draw a perpendicular North-South (NS), on West-East (WE), at the central part. This will represent the central meridian.
5. Divide the central meridian NS into six equal parts, with the help of a pair of compasses, each part being 0.52" long; in such a way that three parts are in the north of equator and the remaining three are to the south of equator. Draw lines parallel to the equator through these points. These lines will represent parallels of 30°, 60°and 90° north and south of the equator.
6. Similarly, draw lines parallel to NS and perpendicular to WE through the points already marked on WE. These lines will represent meridians of 30°, 60°, 90°,120°, 150° and 180° east and west longitudes. This will complete the network of the projection (Fig. 5.3).

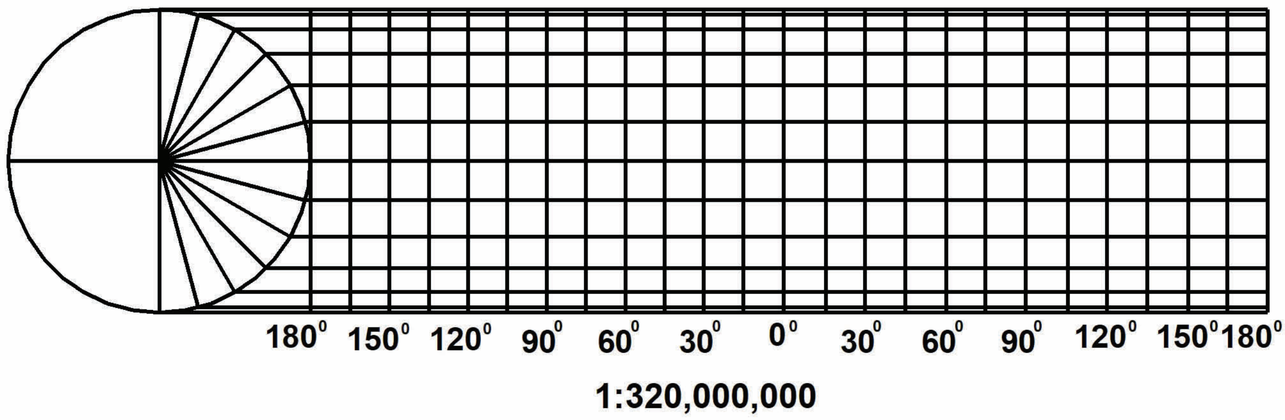


Fig. 5.3: Cylindrical equal area projection.

SAQ 3

Which of the following statements are true and which are false?

a) Inter-parallel spacing decreases rapidly towards the pole.

b) In cylindical equal area projection, the shape of the area does not get highly distorted at the higher latitudes.

c) The projection is also suitable to show the distribution of tropical crops such as coffee, rice and rubber etc.

5.5 MERCATOR'S PROJECTION

This is the most popular amongst all the cylindrical projections. Do you know why this projection is named so? This projection was designed by Gerhardt Kramer of Holland in 1569. Kramer is a Dutch word which is called Mercator in Latin and this projection is popularly known as **Mercator's Projection**. Edward Wright of Cambridge University made certain modifications in this projection in 1599 and in the present day world of cartography we are using its modified form only. The age of navigation had started when Mercator was busy in developing this projection. The sailors used to face great difficulties in reaching their destination in the open and unchartered seas and oceans in the absence of a map which could give an idea of true direction. You might have heard the story of Columbus who wanted to reach India but landed in America. Mercator made a significant contribution to facilitate navigation by making this projection. Most of the European nations sent out their navigators to discover new lands and this projection received unparalleled popularity.

As mentioned earlier, this projection maintains both correct shape and direction and belongs to the family of orthomorphic projections. Therefore, this projection is also known as ***Cylindrical Orthomorphic Projection***. Like all other cylindrical map projections, the scale along parallels is exaggerated away from the equator. In order to maintain correct direction and shape, Mercator increased the scale along meridians in the same ratio as the increase in parallel scale. This is done in the following way:

5.5.1 Properties of Mercator's Projection

i) Shape of parallels and Meridians: All parallels are drawn as straight lines which are parallel and equal in length to the equator. All meridians are drawn as straight lines which are perpendicular to the equator and parallel to one another. They are placed at equal distances and have equal length.

ii) Intersection of parallels and Meridians: The parallels and meridians intersect each other at right angles all over the projection.

iii) Scale along Parallels and Meridians: Scale along the standard parallel i.e. equator is true but it is exaggerated away from the equator. Within the tropics, the exaggeration is not much but in the temperate and polar regions, the exaggeration of the parallel scale increases at an accelerated rate. Pole is a point in Mercator's projection, it is shown equal to the length of equator. Therefore, the exaggeration of the parallel scale is infinite at the poles.

The meridian is almost correct near the equator, but it is exaggerated away from the equator towards the poles. Here, it is worth mentioning that the exaggeration of the meridian scale is in the same ratio as the exaggeration of the parallel scale.

iv) Special Property: This projection has the following two unique properties:

(a) It is an orthomorphic projection in which shapes of different areas are correct. This property is maintained by balancing the 'east-west stretching' with the appropriate 'north-south compression'.

(b) It maintains true direction which means that any straight line on this projection will show the same direction as on the globe.

Demerits: However, this projection has the following demerits:

i) The poles are never projected. This is because the meridians in this projection are equi-spaced whereas the parallels are spaced at intervals that increases away from the equator leading to the projection of pole at infinity.

ii) The sub-polar and polar areas are greatly exaggerated. If we look at the exaggeration of the parallel scale on 60° parallel, the area is increased 2 x 2: 4 times. Similarly, the increase in area at 70°, 75°, 80° and 85° latitudes is 8.5, 15, 33 and 131 times, respectively. The pole is infinite and as such it is futile to show higher latitudes on this projection and this projection is generally drawn up to 80° only. This large scale exaggeration in area often leads to some geographical misconceptions. For example, Greenland is only 1/10th in size to that of South America, whereas on this projection the former looks larger than the latter. Similarly, Alaska looks as large as the United States of America on this projection whereas in reality, latter is about five times larger than the former.

iii) The latitudinal scale increases with increasing distance from the equator.

iv) The Great Circle course is seldom a straight line.

5.5.2 Uses and Limitations of Mercator's Projection

- Very useful for navigation purposes showing sea routes and air routes: Since all the parallels and meridians intersect each other at right angles and both the parallel and meridian scales have the same ratio of exaggeration, any straight line drawn on this projection makes equal angles with all the parallels and meridians and represents a line of constant bearing on the projection. A line of constant bearing that intersects all the meridians at the same angle, such a line keeps constant bearing is known as Rhumb Line or Loxodrome.
- More suitable for a world map and widely used in preparing atlas maps.
- Drainage pattern, ocean currents, temperature, winds and their directions, distribution of worldwide rainfall and other weather elements are appropriately shown on this map.

Major limitations of the projection are as follows:

- Although, this is an orthomorphic projection in which shape as well as direction is preserved, its use is limited to small areas only.
- The exaggeration of scale is different at different latitudes and true orthomorphism is not applicable to large areas such as continents.
- Poles in this projection cannot be shown as 90º parallel and meridian touching them are infinite.

5.5.3 Example along with Calculation and Steps for Construction

Let us discuss methods of construction of Mercator's Projection by explaining one example. As mentioned earlier in this unit, you will be provided with various practical exercises which will be discussed in detail in Laboratory Course (BGGCL-134).

Example 3: Draw a Mercator's projection for the world map on the scale of 1:250,000,000 at 15º interval.

Calculation

Radius of the reduced earth (*R*) is $\frac{250,000,000}{250,000,000}$ = 1inch (Radius of the actual earth is 250,000,000 inch)

Length of Equator $2\pi R$ or $\frac{2x22x1}{7}$ = 6.28 inches

Interval along the Equator $\frac{6.28 \times 15^{\circ}}{360^{\circ}}$ = 0.26 inches

Construction

(i) Draw a line of 6.28" inches representing the equator as EQ.

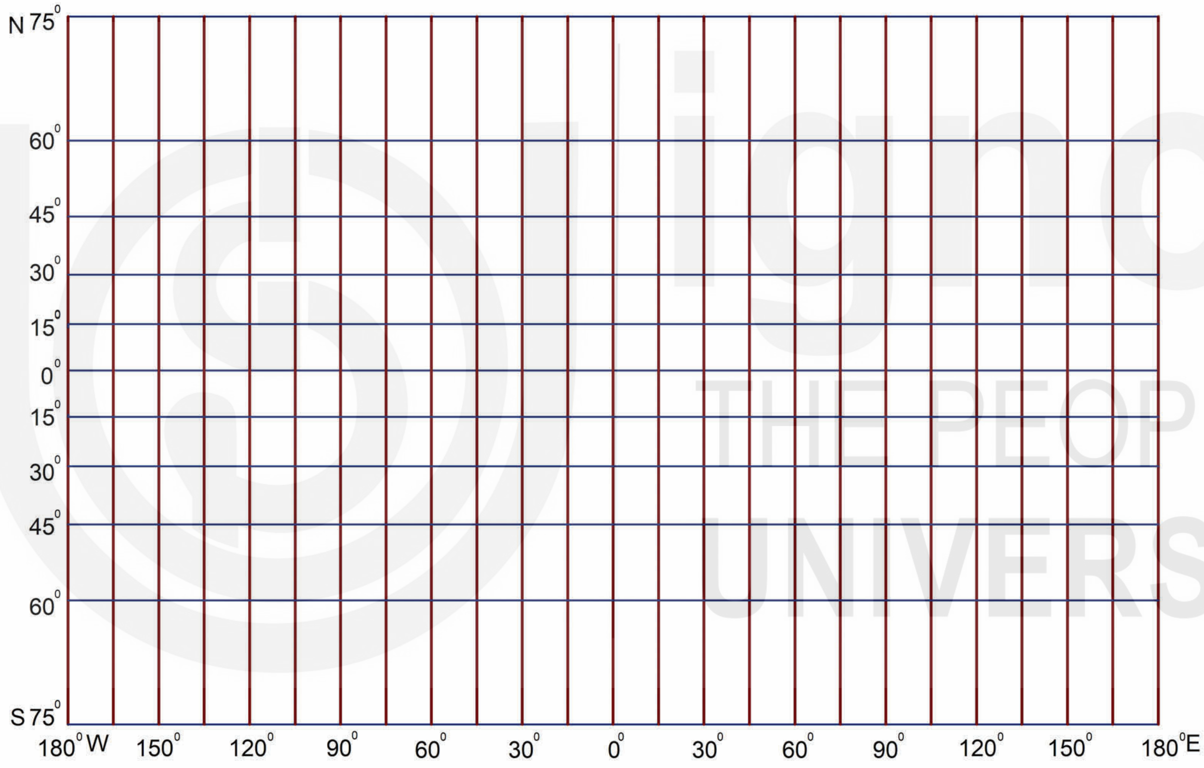
(ii) Divide it into 24 equal parts. Determine the length of each division using the following formula:

$$\frac{\text{Length of Equator} \times \text{interval}}{360}$$

(iii) Calculate the distance for latitude with the help of the table given below:

Latitude	Distance
15º	0.265 × 1 = 0.265" inch
30º	0.549 × 1 = 0.549" inch
45º	0.881 × 1 = 0.881" inch
60º	1.317 × 1 = 1.317" inch
75º	2.027 × 1 = 2.027" inch

(iv) Complete the projection as shown in Fig. 5.4.



R.F. 1:250,000,000

Fig. 5.4: Mercators' projection.

SAQ 4

a) What is Rhumb Line?

b) Why is Mercators' projection known as cylindrical orthomorphic projection?

5.6 SUMMARY

In this unit, you have studied so far:

- In cylindrical map projections, it is assumed that the globe is surrounded by a hollow cylinder and the cylinder touches the globe along the equator. In this condition, the axis of the cylinder coincides with the axis of the globe. The parallels and meridians are transferred from the globe to the inner surface of the cylinder. The cylinder is then cut vertically and unrolled into a flat rectangular sheet of paper.

- Properties common to cylindrical projections are: all parallels are drawn as straight lines which are parallel and equal in length to the equator and meridians are also drawn as straight lines which are perpendicular to the equator. All the meridians are parallel to the prime meridian and parallel to one another. The parallels and meridians intersect each other at right angles everywhere. Scale on the projection is kept correct, reduced or exaggerated depending upon the purpose of the projection.
- We have discussed the three types of cylindrical projections: simple cylindrical projection; cylindrical equal area projection and Mercator's projection.
- Cylindrical projections are best suited for tropical zone lying between 30°N and 30°S latitudes, more so for a narrow belt along the equator. This is because of the fact that the scale along parallels and the meridians remains more or less correct in this zone. Hence the homolographic and orthomorphic properties are well preserved in these areas.
- These projections are not much suited to temperate and polar areas because the scale along parallels and meridians changes drastically in these areas. This results in large scale deformity both in area and shape.

5.7 TERMINAL QUESTIONS

1. Describe common properties of cylindrical projection.
2. Explain properties, uses and limitations of simple cylindrical projection.
3. Discuss various uses and limitations of cylindrical equal area projection.
4. State uses and limitations of Mercator's projection.

5.8 ANSWERS

Self-Assessment Questions

1. a) Cylindrical projections are not much suited to temperate and polar areas because the scale along parallels and meridians changes drastically in these areas. This results in large scale deformity both in area and shape.

   b) Simple cylindrical projection, cylindrical equal area projection, Gall's equal area projection, Mercator's projection and transverse Mercator's projection (Any three).

2. a) equator, all meridians

   b) general purpose maps

   c) equal area, orthomorphic

3. a) True
   b) False
   c) True

4. a) A line which keeps constant bearing is known as rhumb line or loxodrome.
   b) This projection maintains correct shape and direction and belongs to the family of orthomorphic projections. Therefore, this projection is also known as cylindrical orthomorphic projection.

Terminal Questions

1. Points dealing with the common properties of cylindrical projection. Refer to Section 5.2.1.
2. Refer to Sections 5.3.1, 5.3.2 and 5.3.3.
3. Refer to Sections 5.4.2 and 5.4.3.
4. Refer to Sections 5.5.2 and 5.5.3.

5.9 REFERENCES/SUGGESTED FURTHER READING

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UNIT 6

CONICAL PROJECTIONS

Structure

6.1 INTRODUCTION

In this block so far, you have got an introduction to map projections in general and studied about cylindrical projections in particular. Let us first have a quick recap of what you have learnt so far regarding map projections. So now you are aware that, map projection is a network or graticule of parallels and meridians transformed from earth's three dimensional ellipsoid (or spheroid) surface into a two dimensional plane surface. Due to earth's shape, globe is the best way to represent the earth as lines of latitude and longitude are positioned correctly in a globe. Also, the relative size and shape of all the continents, oceans and other area features are truly represented in a globe. However, it is not so handy and it's hard to measure distances in a globe compared to paper maps. This is the reason why we use map projections to flatten it out in two-dimensions. You have also learnt that on the basis of surfaces used for transferring the network of parallels and meridians, there are three types of map projections, that is, ***conical***, ***cylindrical*** and ***zenithal*** projections based on conical, cylindrical and tangential plane surfaces respectively. These three types of map projections are also called ***perspective*** projections which imply the use of light for projecting the graticule of parallels and meridians. Contrary to this, ***non-perspective*** projections does not involve the use of light for projecting the graticule of parallels and meridians but are constructed by certain mathematical or geometrical methods. You may recall that while projecting or flattening the globe in two dimensions, we aim at preserving the following qualities of the portion of globe that is projected, that is, area, shape and direction. However, it is not possible to preserve all the qualities in a single projection. It can either maintain one quality at the cost of other ones. So based on qualitative attributes, map projections may be classified as equal area or ***homolographic*** projections, true shape or ***orthomorphic*** projections and true bearing or ***azimuthal*** projections.

In this unit, you will learn about conical projections. Section 6.2 will give you a general introduction to conical projection. There are several types of conical projections which you will study in the subsequent sections. Section 6.3 deals with conical projection with one standard parallel. This is the simplest form of conical projection. The complex ones being an improvement over this, is dealt with in latter sections, that is, Section 6.4 deals with conical projection with two standard parallels. Then, Section 6.5 will acquaint you with Bonne's projection which is considered to be one of the best projections among the other conical projections. Though, there are some other types of conical projections, but you will learn about them at higher levels.

In the next unit, you will learn about zenithal projections.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define projections and divide them on the basis of projecting surfaces and qualitative attributes;
- describe conical projections and their general properties;
- explain the graphical construction of simple conical projection with one standard and conical projection with two standard parallels and Bonne's projection;
- discuss the properties of simple conical projection with one standard and conical projection with two standard parallels and Bonne's projection; and
- differentiate between simple conical projection with one standard and conical projection with two standard parallels and Bonne's projection.

6.2 INTRODUCTION TO CONICAL PROJECTIONS AND THEIR ATTRIBUTES

As mentioned earlier, conical projections are called so because in these, the developmental surface used for projecting the graticule of parallels and meridians is a cone which is placed over a sphere (Fig. 6.1). The cone touches the globe along a parallel which is called as standard parallel. This is because along this parallel the scale is correct. Refer to Fig. 6.1 to see that the cone is touching the globe along 40°N latitude. 40°N latitude is the standard parallel in this case. Now imagine if light is placed in the centre of globe, then the graticule of parallels and meridians is projected as shadows on the surface of the cone. It is aligned in such a manner that the North Pole is projected to the apex of the cone. When the cone is unrolled into a plane surface, the meridians are either projected as straight or curved lines that converge at the apex of the cone denoted by North Pole. The parallels are projected as arcs of the circles. Refer to Fig. 6.2 to know better.

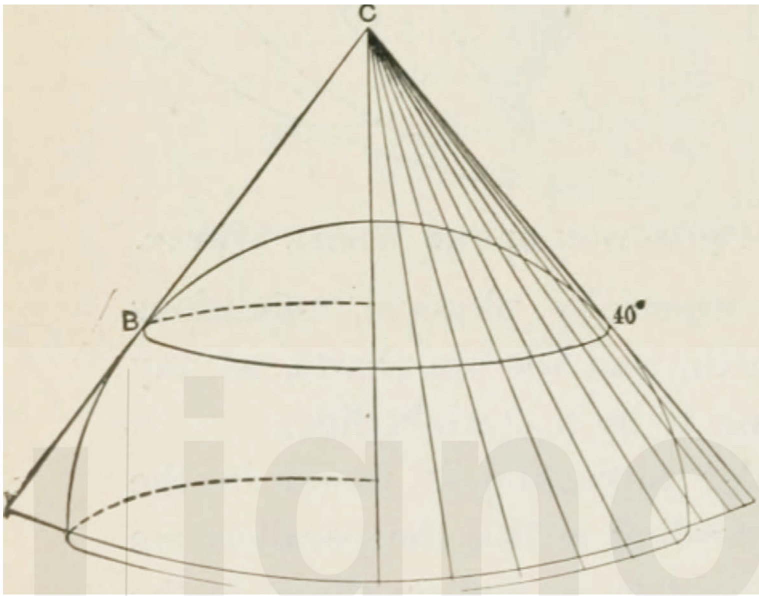

Fig. 6.1: Simple conical projection with one standard parallel.

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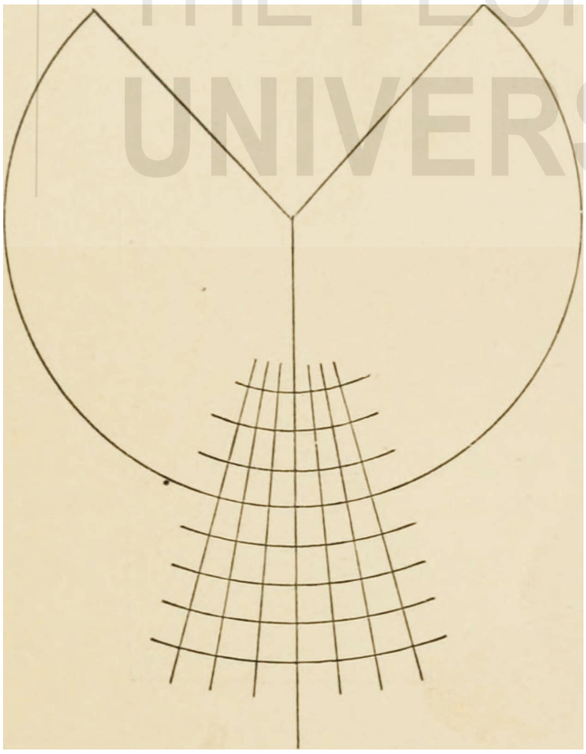

Fig. 6.2 : Projected graticule of parallels and meridians in a simple conical projection.

(Source: https://www.flickr.com/photos/internetarchivebookimages/14803271093/, Public Domain, No copyright restrictions)

This is an example of a simple conical projection or perspective projection. However, all conical projections are not perspective projections like conical projection with two standard parallel, Bonne's Projection etc. which we are going to study later in this unit. Before that, let us get acquainted with some basic attributes of conical projections.

Properties Common to Conical Projections

- All parallels are arcs of concentric circles or concentric curves.
- Meridians in general are straight lines (except for example in Bonne's Projection meridians are smooth curves and only central meridian is a straight line).
- Scale is true along the standard parallel(s).
- It can be orthomorphic or homolographic.
- The pole is represented as an arc or a point.

Let us now get acquainted with simple conical projection with one standard parallel and learn how it is constructed graphically in the next section.

SAQ 1

a) List out any two properties of conical projections.

6.3 SIMPLE CONICAL PROJECTION WITH ONE STANDARD PARALLEL

As the name suggests, in this projection, the cone touches the globe only along one parallel which is regarded as the standard parallel and which is true to scale. Other parallels are represented as concentric circles drawn parallel to standard parallel and are equidistant along the central meridian. The scale along other parallels is not correct. This is the reason why this projection is not suitable for areas having longitudinal extent greater than 20° as the distortion is higher in areas north and south of standard parallel. The meridians are drawn as straight lines radiating from the apex. So all meridians become the radii of the sphere and are true to scale. Let us learn the graphical construction of this projection with the help of an example to get a clear picture of it.

Example 1: Construct the graticule of a simple conical projection when R.F. is 1:64,000,000 and the interval is 5° for an area lying between 40°N to 60° N latitudes and 15°W to 5° E longitudes.

You must have learnt about map scales in Unit 3 of Block 1. So when R.F. or Representative Fraction is 1:64,000,000, it suggests that one unit of the map represents 64,000,000 units on the ground.

Now since the radius of earth is 6,378 km which is rounded off to about 6,400 km or 640,000,000 cm (1 km = 100,000 cm). In our question, the scale is 1:64,000,000. So we can say that 64,000,000 cm is represented as 1 cm on map. So 640,000,000 cm would be represented as:

1/64,000,000 x 640,000,000 cm on map. That is 10 cm on map.

So the radius of earth on map or

Radius of Reduced Earth (R.R.) would be = 640,000,000/64,000,000

= 10 cm

In the question, the latitudinal extent is 40° N to 60° N latitudes.

So the standard parallel can be taken as 50° N latitude (as shown below)

Similarly for selection of central meridian, we follow the same method. Here, 5° W would be the central meridian.

Now for graphical construction of the projection, refer to Fig. 6.3. A circle ABC with radius 10 cm (Radius of reduced earth), is drawn. The centre of the circle is O. From centre O, a line AO is drawn making angle AOB equal to 50° (standard parallel). Since the cone would touch the globe along standard parallel, so from point A, a tangent is drawn to touch the extended polar diameter at point P so that, P represents the apex of the cone. Now AP is the projected radius of the standard parallel. An angle ROC is also drawn equal to 5° interval which marks the interval between the parallels. RC is the true distance between parallels at 5° interval. With RC as an arc, a semi circle is drawn with centre O which meets the line AO at ‘x’. At ‘x’, a perpendicular is drawn to line PO which meets it at ‘y’. So ‘xy’ is the longitudinal distance between two meridians along the standard parallel.

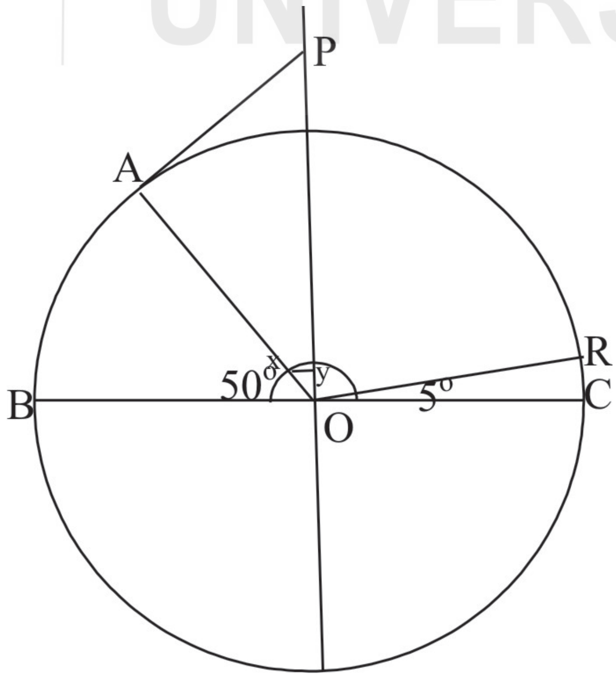

Fig. 6.3: Construction of simple conical projection with one standard parallel.

(Source: Diagram created by the author)

After getting all these required distances the projection can be drawn. Refer to Fig. 6.4 and see that a line PS is drawn as a central meridian. Taking P as the centre, an arc BAC is drawn taking radius as AP (from Fig. 6.3). This represents the standard parallel. Taking RC (from Fig. 6.3), as the distance points are marked on the central median from point A for different parallels. Now other parallels are drawn as concentric circles from point P with the help of distance marked on central meridian for different parallels. The distance xy (Fig. 6.3), is marked along both sides of the standard parallel for drawing other meridians. Straight lines are drawn by connecting them with the pole P.

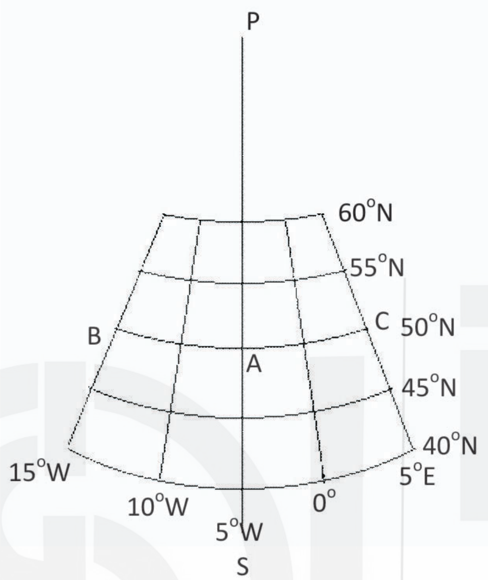

Fig. 6.4: The graticule of simple conical projection with one standard parallel.
(Source: Diagram created by the author)

Now let us list out some important properties of this projection.

Properties of Simple Conical Projection with One Standard Parallel

- All parallels are arcs of concentric circles and are equi-spaced.
- All meridians are straight lines radiating from the pole and intersect the parallels at right angles. The distance between them decreases towards the poles.
- The scale is true along the standard parallel.
- The scale is true along all meridians.
- This projection is suitable for small areas in the mid-latitudes having east-west extent but a small north-south extent as distortion is more away from the standard parallel.

6.4 CONICAL PROJECTION WITH TWO STANDARD PARALLELS

This projection is an improvement over simple conical projection. As the name suggests, you can guess how it is different from the previous one. This is because in this projection we have two standard parallels instead of one as in the previous one. This is an example of a non-perspective projection as a single cone can touch the globe only along one parallel. The standard parallels are selected in such a way that two-thirds of the latitudinal extent is covered in this projection. Since the scale is correct along the two standard parallels, so a greater longitudinal area or north-south extent is correctly represented in this projection.

Let us learn its graphical construction with the help of Example 2.

Example 2: Construct the graticule of simple conical projection with two standard parallels on a scale 1:25,000,000 for an area extending between 20^o-80^o N latitudes and 10^oW to 70^oE longitudes at an interval of 10^o.

Now since the radius of earth is 3,960 miles which is rounded off to about 4,000 miles. Since 1 mile is equal to 63,360 inches. So 4,000 miles is approximately equal to 250,000,000 inches (Hint: 4000X63360= 253,440,000 inches). So the radius of the earth is 250,000,000 inches approximately. In our question, the scale is 1:25,000,000. So we can say that 25,000,000 inches is represented as 1 inch on map. So 250,000,000 inches would be represented as 1/25,000,000 x 250,000,000 inches on map.

So the radius of earth on map or

Radius of Reduced Earth (R.R.) would be = 250,000,000/25,000,000

= 10 inches

Since there are two standard parallels, these should be selected in such a manner that maximum latitudinal extent (up to 2/3[rd]), comes between these two parallels. So if the latitudinal extent is 20^o-80^o N latitudes with the interval of 10^o, and if we take standard parallels as 30^oN and 70^oN latitudes, then about two-third of latitudinal extent is covered between them. Since the longitudinal extent is 10^oW to 70^oE longitudes, so the central meridian is selected to be 30^o E longitude.

Now refer to Fig. 6.5 and Fig. 6.6 to learn how it is constructed.

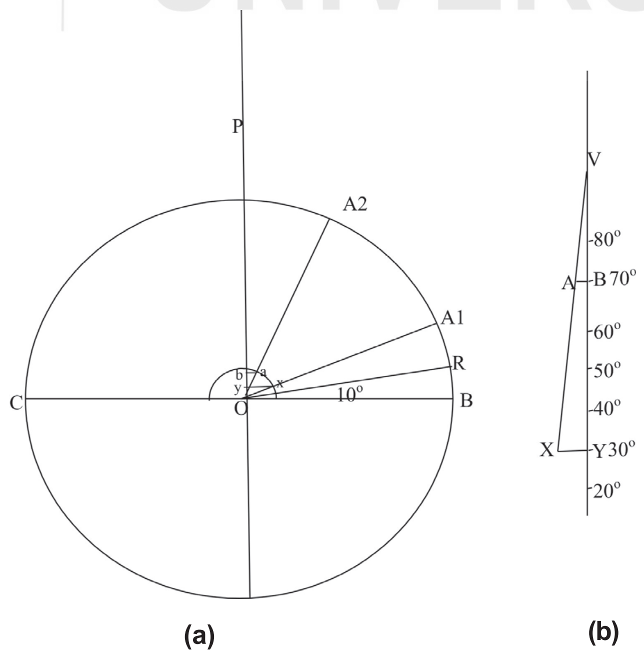

Fig. 6.5: Construction of conical projection with two standard parallels.

(Source: Diagram created by the author)

In Fig 6.5, a circle with radius equal to 10" (R.R.) is drawn. The centre of the circle is marked as 'O'. From centre O, lines A1O and A2O are drawn making angles A1OB and A2OB equal to 30° and 70° respectively (standard parallels). An angle ROB is also drawn equal to 10° interval which marks the interval between the parallels. A semi circle is also drawn with RB as an arc, at centre O which meets the line A1O at a point 'x'. From 'x', a perpendicular is drawn to line PO which meets it at 'y'. So 'xy' is the longitudinal distance between two meridians along 30°N standard parallel. Similarly, this small semi- circle drawn at O also cuts the line A2O at 'a' from which a perpendicular is drawn to meet the line PO at 'b' as shown in Fig. 6.5(a). So 'ab' is the longitudinal distance between two meridians along 70°N standard parallel.

Now refer to Fig. 6.5(b) and see that a line VBY is drawn as central meridian and taking arc distance as RB, points are marked as the parallels from 20°-80° N latitudes on the line. The standard parallels 30°N and 70° N latitudes are at point Y and B respectively. From these points, perpendicular lines XY and AB are drawn with length equal to 'xy' and 'ab' of Fig. 6.5(a). The points X and A are joined by a straight line to meet the line VBY at V. This marks the exact location of point V on line VBY. Now VY and VB become the radii for drawing standard parallels 30° N and 70° N latitudes respectively.

Now refer to Fig. 6.6 and see that a line VBY is drawn as Central Meridian (30°E longitude) and it is divided taking the interval RB (as done in Fig. 6.5b), to mark the intersection of all parallels on it. The intersections of 30° N and 70° N latitudes on the central meridian are marked as Y and B respectively. Now from point Y, point V is marked on the central meridian taking distance VY as shown in Fig. 6.5(b). V becomes the vertex of the cone. Taking VB and VY as radii of concentric circles, two arcs are drawn as two standard parallels. Other parallels are also drawn as concentric circles taking arc distance from vertex

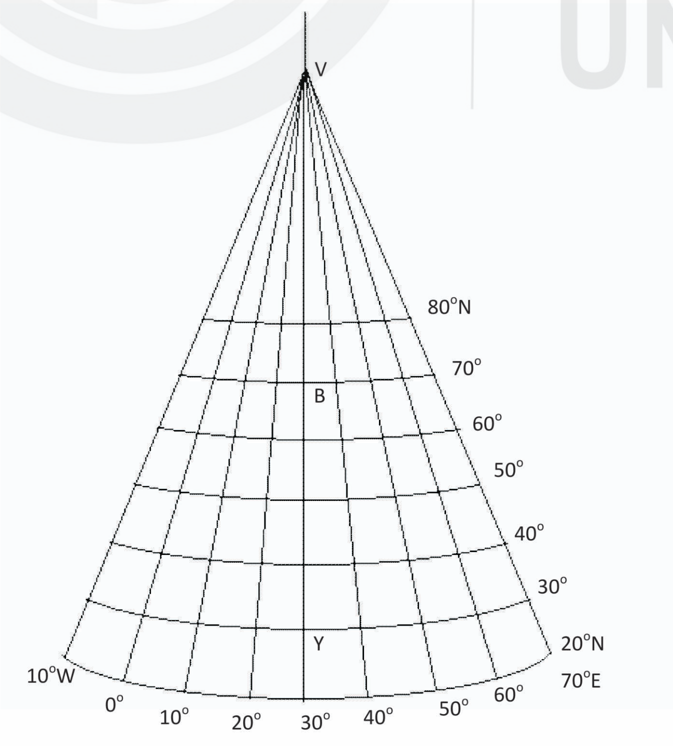

Fig. 6.6: The graticule of simple conical projection with two standard parallels.

(Source: Diagram created by the author)

'V' to their respective intersections already marked along the central meridian. Along 30° N and 70° N latitudes, the distance between the meridians are marked on both sides of central meridian taking distances as xy and ab respectively. The corresponding points on both the standard parallels are joined by straight lines and extended polewards upto 80° N latitudes and equatorwards upto 20° N latitudes as per the latitudinal extent given in Example 2. Refer to Fig. 6.6 to understand better.

You must always remember that the metric and English systems both are commonly used in the construction of map projections. Here, we have given Example 1 in metric system and Example 2 is explained in inches and miles for gaining knowledge in both the systems.

Let us now list the properties of conical projection with two standard parallels.

Properties of Conical projection with two Standard Parallels.

- All parallels are arcs of concentric circles.
- All meridians are straight lines radiating from the pole as radii of concentric curves.
- The scale is true along both the standard parallels.
- The scale is true along all the meridians.
- The distances between the standard parallels are shorter than their actual distances while beyond them they are longer than their actual distances.
- As mentioned earlier, this projection is an improvement over the conical projection with one standard parallel as it is suitable for comparatively large areas of mid-latitudes like that of Canada and Russia etc. This is because of the two standard parallels which reduces the north-south distortion.

SAQ 2

List out two differences between simple conical projection with one standard parallel and simple conical projection with two standard parallels.

6.5 BONNE'S PROJECTION

It is a special case of conical projection named after a French cartographer Rigobert Bonne, who designed this projection. It is different from the former two projections because in this all the parallels are drawn true to scale. However, only one parallel is considered as standard parallel and hence its radius is determined. The curvature of other parallels depends on the standard parallel. For drawing the meridians, all the parallels are divided separately and truly and the points so obtained are joined by smooth curves. You will get a clear picture of it once you learn its graphical construction with the help of Example 3.

Example 3: Suppose the question is to construct the graticule of Bonne's projection when R.F. is 1:320,000,000 and the interval is 10° for an area lying between 35° N to 75° N latitudes and 0° to 60° E longitudes.

Since R.F. = 1:320,000,000,

So Radius of the Reduced Earth (R.R.) = 640,000,000/320,000,000

= 2 cm

Since the latitudinal extent is 35° N to 75° N, so central parallel is selected to be 55° N latitude.

Since the longitudinal extent is 0° to 60° E, so the central meridian is selected to be 30° E longitude.

Now refer to Fig. 6.7 and see that a circle with radius equal to 2 cm (R.R.), is drawn. The centre of the circle is marked as 'O'. From centre O, a line AO is drawn making angle AOB equal to 55° (standard parallel). Similarly, other lines are also drawn like A1O, A2O, A3O and A4O such that angles A1OB, A2OB, A3OB and A4OB are equal to other parallels, 35°, 45°, 65° and 75° respectively. A tangent is drawn from point 'A' to touch the extended polar diameter at point P. So AP becomes the projected radius of the standard parallel. An angle ROB is also drawn equal to 10° interval which marks the interval between the parallels. Arc RB is the true distance between the parallels at 10° interval along central meridian. Now other parallels are marked by taking arc distance RB on the central meridian from point of intersection of standard parallel on the central meridian. In Fig. 6.7, you can see that a semi circle is also drawn with RB as an arc, at centre O which meets the line AO at a point 'x'. From 'x', a perpendicular is drawn to line PO which meets it at 'y'. So 'xy' is the longitudinal distance between two meridians along the standard parallel. Similarly this small semi- circle drawn at O also cuts other lines A1O, A2O, A3O and A4O at different points from which perpendiculars are drawn to meet the line PO as shown in Fig. 6.7. These are the intervals between meridians along respective parallels. After marking these intervals on respective parallels, the meridians are drawn as smooth curves.

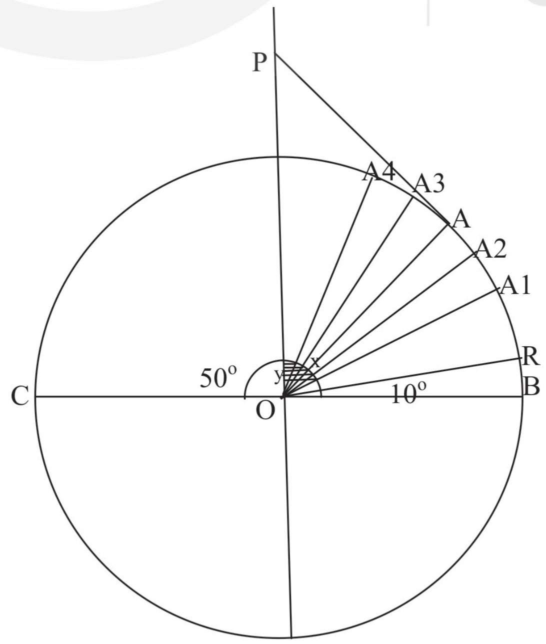

Fig. 6.7: Construction of Bonne's projection.
(Source: Diagram created by the author)

Refer to Fig. 6.8 and see that a line PS is drawn as a central meridian. Taking P as the centre, an arc is drawn taking radius as AP (from Fig. 6.7). This represents the standard parallel. Now other parallels are drawn as concentric circles from point P after marking the point of intersection of other parallels on the central meridian from point A taking arc distance RB (Fig. 6.7) as the distance between the parallels on central meridian.

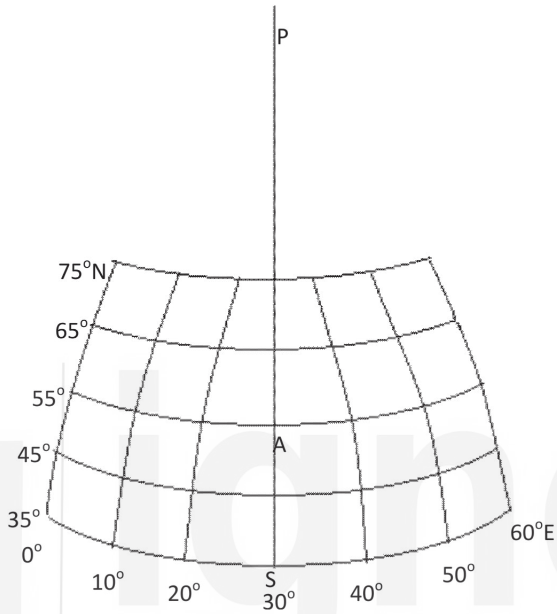

Fig. 6.8: The graticule of Bonne's projection.
(Source: Diagram created by the author)

The perpendicular distances obtained from intersections along small semi-circle for different parallels and the line PO (from Fig. 6.7) are marked along different parallels in Fig. 6.8 and meridians are joined by smooth curves as mentioned earlier.

Before ending, let us learn about all the important properties of Bonne's projection.

Properties of Bonne's Projection

- All parallels are concentric curves. However, their curvature depends on the curvature of the selected standard parallel for construction.
- All meridians are smooth curves except the central meridian which is a straight line.
- The scale is true along all the parallels as all of them are drawn true to scale.
- The scale is correct along the central meridian only. This is the reason why shape gets distorted away from the central meridian.
- This is an equal area projection as in this, the area of each quadrangle is made equal to the corresponding quadrangle on the globe. Both height and base are true to scale.

- As this is an equal area projection, it is suitable for maps of Europe, North America and Australia etc. It is used for maps of all continents except Africa. Sinusoidal projection is suitable for drawing maps of Africa, which is a special case of Conical projection, but you will study about sinusoidal projection at higher levels. Bonne's projection is also used for topographical maps of countries like Netherlands, Belgium and Switzerland etc.

SAQ 3

How is Bonne's projection different from the simple conical projections with one and two standard parallels?

6.6 SUMMARY

In this unit, you have studied so far:

- Map projection is a network or graticule of parallels and meridians transformed from earth's three dimensional surface into a two dimensional plane surface.
- On the basis of surfaces used for transferring the network of parallels and meridians, there are three types of map projections, that is, ***conical***, ***cylindrical*** and ***zenithal*** projections based on conical, cylindrical and tangential plane surfaces respectively.
- Based on qualitative attributes, map projections are classified as equal area or ***homolographic*** projections, true shape or ***orthomorphic*** projections and true bearing or ***azimuthal*** projections.
- Simple conical projection with one standard parallel is the simplest of all the conical projections with only one standard parallel drawn true to scale. This projection is suitable for small areas in the mid-latitudes having east-west extent but a small north-south extent.
- Conical projection with two standard parallels is an improvement over the simple conical projection with one standard parallel as two parallels are drawn true to scale. This is suitable for comparatively large areas of mid-latitudes with greater latitudinal extent.
- Bonne's projection is an equal area projection where all the parallels are standard parallels. It is suitable for maps of Europe, North America, Australia and all continents except Africa.

6.7 TERMINAL QUESTIONS

1. Define projection. Briefly describe the properties of Conical Projection with one standard parallel.
2. Explain the salient features of Bonne's projection.
3. Describe how simple conical projection with two standard parallels is constructed graphically. Give suitable sketches to support your answer.

6.8 ANSWERS

Self-Assessment Questions

1. Two properties of conical projections are:

   i) All parallels are arcs of concentric circles or concentric curves.

   ii) Scale is true along standard parallel(s).

2. The two differences between simple conical projection with one standard parallel and simple conical projection with two standard parallel is that the former is having only one standard parallel which is true to scale while in the latter there are two standard parallels along which the scale is correct. The second difference is that since the scale is correct along two standard parallels in the latter one, so scale is correct along greater latitudinal extent and so, it is suitable for showing countries in mid-latitudinal areas having greater north-south extent like Russia and Canada etc., while the former one is suitable for areas in mid-latitudes having only a small north-south extent.

3. Bonne's projection is different from simple conical projection with one standard and conical projection with two standard parallels as in Bonne's projection all the parallels are standard parallels while in simple conical projection with one standard parallel only one parallel is standard parallel and in simple conical projection with two standard parallels, two parallel are standard parallels. Bonne's projection is an equal area projection, while the other two are not. In Bonne's projection only central meridian is a straight line and other meridians are smooth curves, while in the other two all meridians are straight lines and scale is correct along all the meridians. In Bonne's projection, scale is correct only along central meridian and there is distortion away from the central meridian.

Terminal Questions

1. First give the definition of projection and explain how projections are classified on the basis of different projecting surfaces. Then describe the properties of simple conical projection with one standard parallel. Refer to the Sections 6.1 and 6.3.

2. First list and then also explain the salient features of Bonne's projection. Refer to the Section 6.5.

3. Give an example and draw rough sketches to describe how simple conical projection with two standard parallels is constructed graphically. Refer to the Section 6.4.

6.9 REFERENCES/SUGGESTED FURTHER READING

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UNIT 7

ZENITHAL PROJECTIONS

Structure

7.1 INTRODUCTION

In this block so far, you have been introduced to various types of map projections. You can now divide projections on the basis of projecting surfaces. You can also divide them on the basis of qualitative attributes preserved. You have also studied about cylindrical projections and conical projections and some of their types. You have learnt to draw their graticule of parallels and meridians through graphical method for some conical and cylindrical projections. In this unit, you will learn about the zenithal projections.

Section 7.2 will introduce you to zenithal projections in general and their attributes. In this unit, you will learn two types of zenthal projections which are also perspective projections in nature. Based on the position of the source of light and position of the tangent plane, two types of zenithal projections have been discussed here. Section 7.3 will acquaint you with zenithal gnomonic polar case and Section 7.4 will discuss about zenithal stereographic polar case. You will also learn about the construction of these two projections graphically.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define zenithal projections and list its basic properties;
- divide zenithal projection on the basis of the position of tangent plane and on the basis of placement of light source;
- illustrate the construction of zenithal gnomonic polar and zenithal stereographic polar projections; and
- list the properties of zenithal gnomonic polar and zenithal stereographic polar projections and differentiate between them.

7.2 INTRODUCTION TO ZENITHAL PROJECTIONS AND THEIR ATTRIBUTES

Since you have studied that projections can be divided into different types on the basis of projecting surfaces, can you now define zenithal projections? The projection which is obtained by projecting graticule of latitudes and longitudes on a plane tangent to the globe, it is called a zenithal projection.

Let us learn about some basic properties of zenithal projections.

Properties Common to Zenithal Projections:

- One important property of zenithal projection is that they have true bearings from the centre or we can say that directions of all points from the centre are correct. That is why they are also called ***azimuthal projections***.
- The projecting surface is tangent to the globe.
- Shape is distorted away from the centre.

Now let us learn about different types of zenithal projections.

7.2.1 Types of Zenithal Projections

Zenithal projections are divided into two broad types, that is, perspective and non-perspective projections. If light is used as a source for projecting the graticule of parallels and meridians, then it is called ***perspective zenithal projection***. Those which do not involve the use of light for projecting the graticule of parallels and meridians are called ***non-perspective zenithal projections***.

Perspective zenithal projections are further divided into three types on the basis of position of this light source. If the source of light is placed at the centre of the projecting globe, it is called a ***gnomonic zenithal projection***. If the source of light is placed diametrically opposite to the point of contact of the tangential plane, it is called a ***stereographic zenithal projection***. Now when the light source is at infinity, so that the rays of light are parallel, the resultant projection is called an ***orthographic zenithal projection***. Refer to Fig. 7.1 to understand better. In the figure you can see the different position of light sources in the projecting globe (in gnomonic, stereographic and orthographic cases) in the lower portion and the respective projected graticule of parallels and meridians in the upper portion.

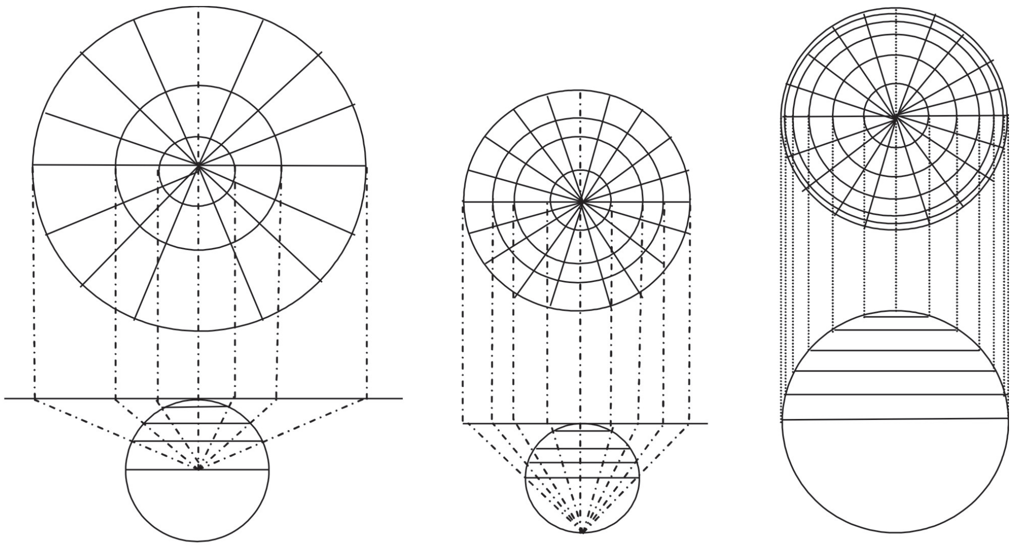

Fig. 7.1: Perspective zenithal projections based on position of source of light.
(Source: Diagram created by the author)

Each of these perspective zenithal projections can further be divided into three types depending on the position of the tangent plane thus bringing a total of nine types of perspective zenithal projections. The tangent plane can be placed at three different positions, that is, at the poles, at the equator and between the poles and equator. Refer to Fig. 7.2 to learn better. If the tangent plane is touching any of the poles (either North or South), it is called ***Polar case of Zenithal projection***. If the tangent plane is placed at a point in the equator, it is called ***Equatorial case of Zenithal Projection***. If the tangent plane is placed at any point between the poles and equator, it is ***Oblique Zenithal Projection***. Thus, we see that altogether we have nine types of perspective zenithal projections. Two of the important non-perspective zenithal projections are zenithal equi-distant projection and zenithal equal-area projection.

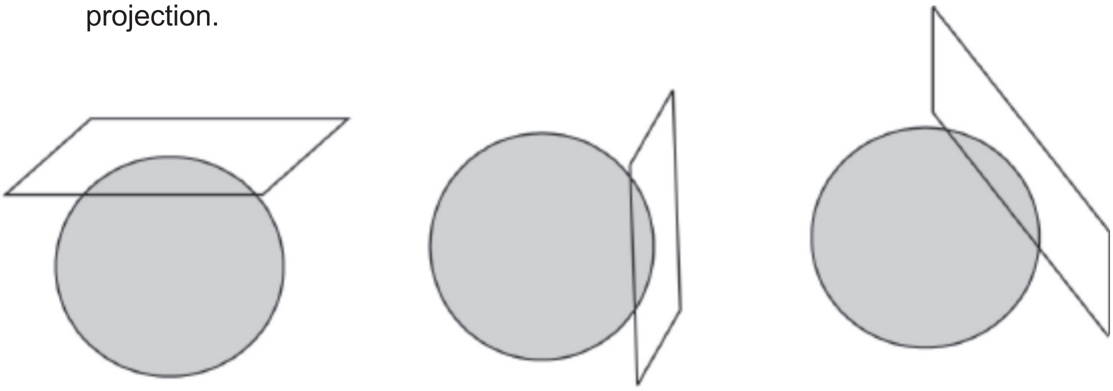

Fig. 7.2: Different positions of tangent plane for zenithal projections.
(Source: Diagram created by the author)

In this unit, we will learn about two perspective zenithal projections in detail, that is, zenithal gnomonic polar case and zenithal stereographic polar case in detail in the coming sections.

SAQ 1

How many different types of perspective zenithal projections are there?

7.3 ZENITHAL GNOMONIC POLAR CASE

Seeing the name of the projection you can now define zenithal gnomonic polar projection as a projection in which the light source is placed at the centre of the projecting globe and the tangent plane touches either of the two poles. In Fig. 7.3, you can see that the tangent plane is touching the pole on which the shadows of latitudes and longitudes are projected and the light source is kept at the centre of the projecting globe. Then one thing you can notice that is difficult to project the equator on the tangent plane as it becomes infinite. Because of this reason, it is impossible to draw an entire hemisphere in this projection.

Now let us get acquainted with the graphical construction of this projection with the help of Example 1.

Example 1: Construct a gnomonic polar projection for the northern hemisphere when R.F. is 1:320,000,000 and the interval is 15°.

First of all, you need to find the radius of reduced earth (R.R.).

From the previous unit, you may recall that radius of the earth is approximately 4,000 miles. Since 1 mile is 160,000 cm, so if we convert the radius of earth in centimetres it comes to 640,000,000 cm (Hint: 4,000X160,000= 640,000,000).

Since the scale of the projection is R.F. = 1:320,000,000

So the radius of reduced earth (R.R.) = 640,000,000 / 320,000,000 = 2 cm

Refer to Fig 7.3 and see that a circle with radius 2 cm is drawn with centre O where light source is kept. The plane XY is tangent to the globe at 90° N latitude or the North Pole.

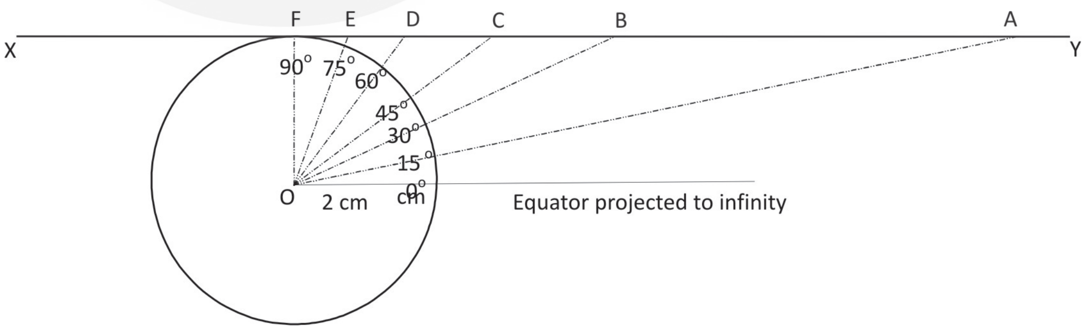

Fig. 7.3: Construction of zenithal gnomonic polar projection.
(Source: Diagram created by the author).

Lines OA, OB, OC, OD, OE and OF represent the latitudes of 15°, 30°, 45°, 50°, 75° and 90° drawn from centre O and projected on the tangent plane at points A, B, C, D, E and F, respectively. Now FA, FB, FC, FD and FE becomes the projected radii for the parallels 15°, 30°, 45°, 50° and 75° respectively with the help of which concentric circles denoting the parallels of latitudes with centre F are drawn. North Pole is represented by point F as the projecting surface is tangent to the North Pole. Now you can easily draw Meridians with 15° interval with the help of a protractor as shown in Fig. 7.4.

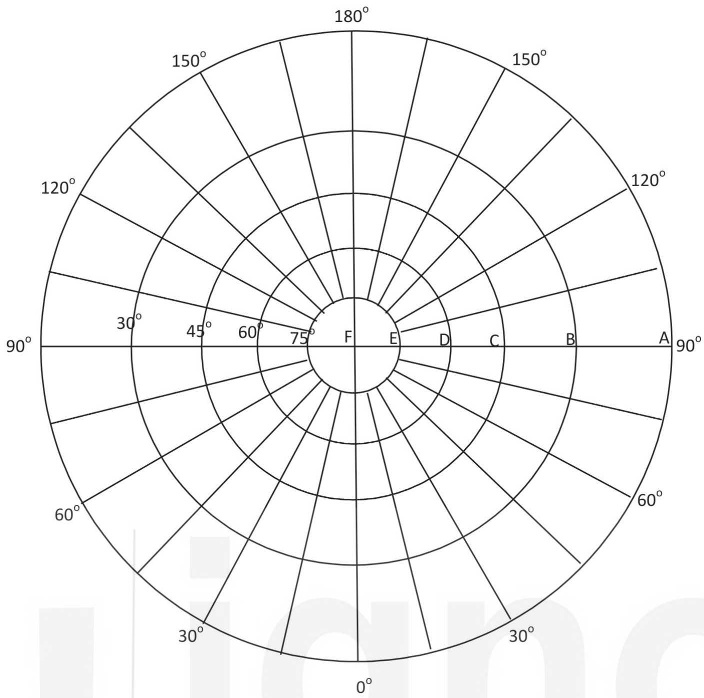

Fig. 7.4: Graticule of parallels and meridians of zenithal gnomonic polar projection.

(Source: Diagram created by the author)

Before we study another type of zenithal projection, let us go through the properties of zenithal gnomonic polar projection.

Properties of Zenithal Gnomonic Polar Projection

- The parallels of latitude are concentric circles.The parallels are not equi-spaced. The distance between them increases away from the centre.
- The meridians of longitudes are straight lines radiating from the centre. They are great circles as their planes pass through the centre of the sphere. So they show correct bearing. Due to this reason, this projection is used for navigational purposes as any straight line drawn in the map between the two place shows the shortest distance between them in this projection.
- The scale gets distorted away from the centre. This is the reason it is suitable for very small areas near the poles, say from poles to 60° in both the hemispheres.
- It is impossible to show the map of one hemisphere in this projection as the equator becomes infinite and cannot be projected on the tangent plane.

SAQ 2

List the advantages and disadvantages of zenital gnomonic polar projection.

Now let us study the zenithal stereographic polar projection in the next section.

7.4 ZENITHAL STEREOGRAPHIC POLAR CASE

Now as the name suggests, you can very well guess that it is a type of perspective zenithal projection, in which the source of light is kept diametrically opposite to the tangent plane which is touching any of the poles. This is definitely an improvement over the previous projection discussed here that is, zenithal gnomonic polar case. This is because an entire hemisphere can be represented in this projection. This projection is also called polar orthomorphic projection as the correct shape is maintained for small areas in this projection. Like the previous projection, this projection also has correct bearing or direction. Thus, we can say that this projection is both orthomorphic and azimuthal.

Now let us learn the graphical construction of this projection with the help of example 2.

Example 2: Construct a stereographic polar projection for the southern hemisphere when R.F. is 1:320,000,000 and the interval is 10°.

First of all you need to find the radius of reduced earth (R.R.)

The radius of earth is approximately 4,000 miles. Since 1 mile is equal to 160,000 cm, so if we convert the radius of earth in centimetres it comes to 640,000,000 cm (Hint: 4,000X160,000= 640,000,000).

Since the scale of the projection is R.F. = 1:320,000,000.

So the radius of reduced earth (R.R.) = 640,000,000 / 320,000,000 = 2 cm

Now refer to Fig 7.5 and see that a circle with radius 2 cm (R.R.), is drawn with centre O. The plane XY is tangent to the globe at 90° S or the South Pole represented by point N. The source of light is diametrically opposite to the South Pole at point S.

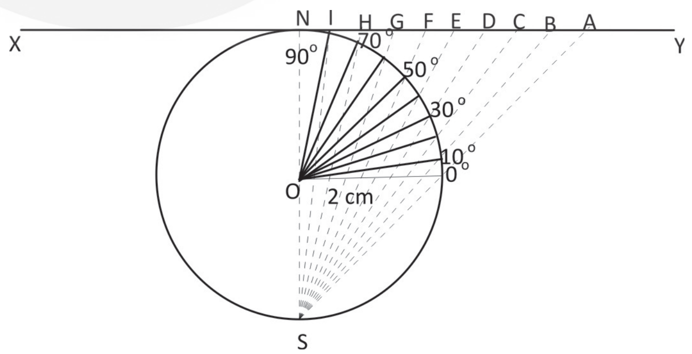

Fig. 7.5 Construction of Zenithal Stereographic Polar Projection
(Source: Diagram generated by the author)

As per question, the interval is 10°. So you can see angles of 10°, 20°, 30°, 40°, 50°, 60°,70°, 80°, and 90° are drawn denoting the latitudes. The latitudes of 0°,10°, 20°, 30°, 40°, 50°, 60°,70°, 80° and 90° are projected at points A, B, C, D, E, F, G, H, I and N respectively on the tangent plane XY from the light source at S. So NA, NB, NC, ND, NE, NF, NG, NH and NI becomes the radii for the parallels 0°,10°, 20°, 30°, 40°, 50°, 60°,70° and 80° respectively with the help of which concentric circles denoting the parallels of latitudes with centre N are drawn. South Pole is represented by point N as the projecting surface is tangent to the globe at South Pole. Now meridians can easily be drawn with 10° interval with the help of a protractor as shown in Fig. 7.6.

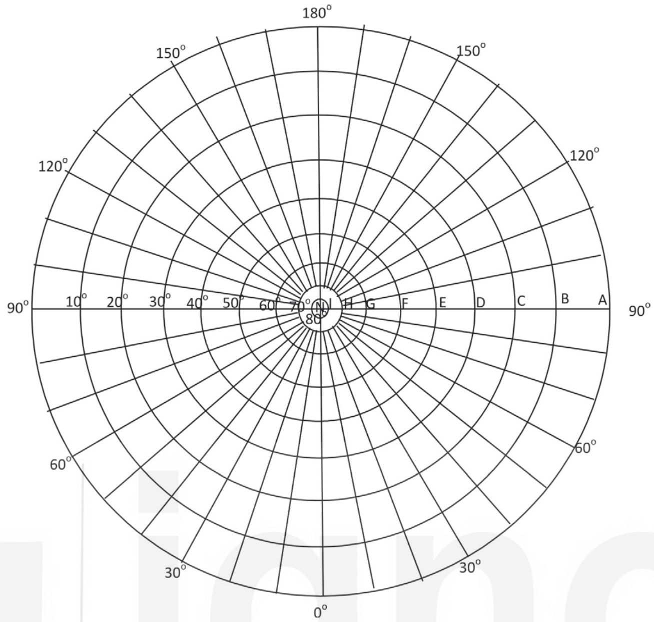

Fig. 7.6: Graticule of parallels and meridians of zenithal stereographic polar projection.

(Source: Diagram created by the author)

Before we conclude, let us also list out the important properties of this projection.

Properties of Zenithal Stereographic Polar Projection

- The parallels of latitude are concentric circles. They are not equi-spaced as the distance between them increases away from the centre. However, this increase or exaggeration is less compared to zenithal gnomonic polar projection.
- The meridians of longitudes are straight lines radiating from the centre. Distance between them also increases towards the equator. However, this is in the same proportion with the increase in distance between the parallels towards the equator. Due to this reason, correct shape for small area is maintained in this projection. So it is also an orthomorphic projection.
- The scale has true bearings from centre to any other point. So it is suitable for navigational purposes.
- This projection is suitable to show the maps of two hemispheres as the equator can be projected on map.

SAQ 3

Give two similarities and two differences between zenithal ghomonic polar case and zenithal stereographic polar case.

7.5 SUMMARY

In this unit, you have studied so far:

- The projection which is obtained by projecting graticule of latitudes and longitudes on a tangent plane, is called a zenithal projection. They are also called ***azimuthal projections*** as they are having correct bearing or direction.
- Zenithal projections are divided into two broad types, that is, perspective and non-perspective projections, based on the use of light or non-involvement of light in projection, respectively.
- Perspective zenithal projections are further divided into three types on the basis of position of this light source, that is ***gnomonic*** (light source is in centre of projecting globe), ***stereographic*** (light source is diametrically opposite to the tangent plane of the projecting globe), and ***orthographic*** (light rays are parallel and coming from infinity), projections.
- Each of these perspective zenithal projections can further be divided into three types depending on the position of the tangent plane, that is ***polar*** (if the tangent plane is touching any of the poles), ***equatorial*** (if the tangent plane is touching any point on equator), and ***oblique*** (if the tangent plane is touching any point between the poles and equator).
- Zenithal gnomonic polar projection is a projection in which the light source is placed at the centre of the projecting globe and the tangent plane touches either of the two poles. The parallels of latitude are concentric circles.The meridians of longitudes are straight lines radiating from the centre. It is impossible to show the map of one hemisphere in this projection as the equator becomes infinite and cannot be drawn on map. It is suitable for very small areas near the poles especially for navigational purposes.
- Zenithal stereographic polar projection is an improvement over zenithal gnomonic polar projection. This is because an entire hemisphere can be represented or projected in this projection. The parallels of latitude are concentric circles. The meridians of longitudes are straight lines radiating from the centre. Distance between the meridians increases towards the equator. However, this is in the same proportion with the increase in distance between the parallels towards the equator due to which the correct shape is maintained. Thus, this projection is both orthomorphic and azimuthal.

7.6 TERMINAL QUESTIONS

1. List the properties of zenithal gnomonic polar projection. Enhance your answer with the help of a rough sketch.
2. List the properties of zenithal stereographic polar projection. Enhance your answer with the help of a rough sketch.

7.7 ANSWERS

Self Assessment Questions

1. Altogether, there are nine types of perspective zenithal projections. On the basis of position of the source of light, perspective zenithal projections are of three types, that is, gnomonic, stereographic and orthographic zenithal projections. Each of these types of perspective zenithal projection is further divided into three types each based on different position of tangential plane projecting surface giving rise to polar, equatorial and oblique cases.

2. One important advantage of zenithal gnomonic polar projection is that it shows correct bearings. Due to this reason, it is used for navigational purposes. The disadvantage is that there is too much of exaggeration away from the centre and it is only suitable for mapping very small areas between poles to about 60^{o} (North or South), latitudes. Entire hermisphere cannot be represented in this projection as equator is projected to infinity.

3. The two similarities between zenithal gnomonic polar projection and zenithal stereographic polar projection are that in both the projections, the bearing or directions are correct due to which they are used in navigational chart for areas around the poles. Both the projections are perspective projections in which the tangent plane is touching any of the two poles (north or south), of the projecting globe.

   The two differences between these projections are that in zenithal gnomonic polar projection, light source is placed in the centre of the projecting globe, while in zenithal stereographic polar projection light source is placed diametrically opposite to the point of contact of the tangent plane. In the former, one hemisphere cannot be represented while in the latter one hemisphere can be represented.

Terminal Questions

1. List all the properties of zenithal gnomonic polar projection as given in Section 7.3. Explain the properties giving a rough sketch.

2. List all the properties of zenithal stereographic polar projection as given in Section 7.4. Explain the properties giving a rough sketch.

7.8 REFERENCES/SUGGESTED FURTHER READING

- Singh, L.R. (2009). *Fundamentals of Practical Geography.* Allahabad: Sharda Pustak Bhawan.
- Singh, R.L. and Singh, Rana. P.B. (1998). *Elements of Practical Geography.* New Delhi: Kalyani Publishers.
- Mishra, R.P. (2002). *Fundamentals of Cartography.* New Delhi: Concept Publishing Company.

GLOSSARY

Azimuthal Projections: Projections maintaining correct direction and distance on the map are called azimuthal or true bearing projections.

Bonne's Projection: It is a conical equal area projection where all the parallels are standard parallels.

Concentric Circles: Circles having a common centre.

Conformal or Orthomorphic Projections: These projections preserve angles and local shapes but not for larger areas.

Conical Projections: In these projections, the developmental surface used for projecting the graticule of parallels and meridians is a cone which is placed over a sphere.

Cylindrical Equal Area Projection: This projection is also called Lambert's Cylindrical Projection in which the distance between latitude decreases towards the higher latitudes.

Cylindrical Projection: In this projection, the radius of cylinder is equal to the radius of the globe, surrounds the globe and touches it at the equator.

Developable Surfaces: The cylinder, the cone and the plane are known as developable surfaces.

Equal area Projections: If the area on the map of any object equivalent to its area on the globe.

Equidistant Projections: Scale is at uniformity along meridians and the equator.

Geographical Coordinates: The lines of latitudes and longitudes are called geographical coordinates.

Gnomonic Case: When the source of light is placed at the centre of the projecting globe.

Graticule: The network of parallels and meridians construct perpendicular to each other.

Great Circle: A line may be drawn from center of the globe that divides sphere into two halves is called the great circle.

Latitude: Latitude is a parallel line. Latitudes or parallels are arranged in north-south position.

Longitude: Longitude is a vertical line. These lines connect the north and south poles and divide the latitudes at right angles. Longitudes or meridians are arranged in east-west position.

Loxodrome: Loxodrome or rhumbline is a line intersecting each meridian at the same angle.

Map Projection: The transformation of earth's 3D surface into two dimentional flat surface on a map using mathematical formulae.

Mercator's Projection: It maintains the correct shape and direction. The scale along parallels is exaggerated while moving away from the equator as like of all other cylindrical map projections.

Non-perspective Projections: Mathematically derived projections are known as non-developable or non-perspective projections.

One Standard Parallel: The projection in which scale is true only along one parallel.

Orthographic Case: When the light source is at infinity, so that the rays of light are parallel.

Perspective Projections: These are drawn with the help of light source.

Secant Case: When the contact between the earth's surface and the plane of map projection is along two lines called as secant.

Sphere: It is derived based on a circle.

Spheroid: It is derived based on an ellipse. The shape of an ellipse is defined by two radii.

Standard Parallel: The parallel which is true to scale.

Stereographic Case: When the source of light is placed diametrically opposite to the point of contact of the tangential plane.

Tangent Case: The point or line of contact between the globe and the surface of map projection.

Two Standard Parallels: The projection where scale is true along two parallels which are selected in such a way that about two-third of the latitudinal extent of the projection is covered between them.

Zenithal Projection: The projection which is obtained by projecting graticule of latitudes and longitudes on a plane which is tangent to the globe.