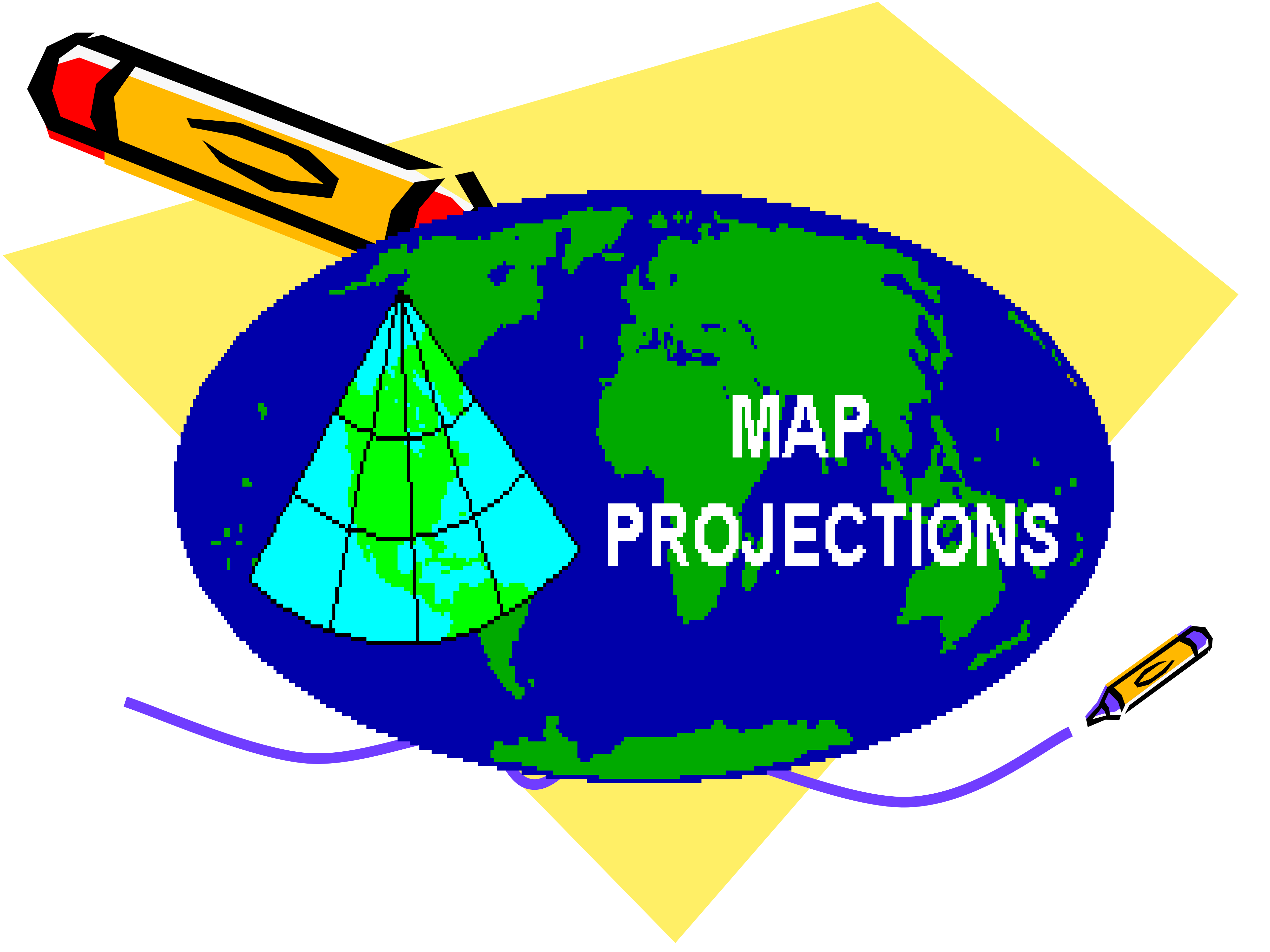

MAP
PROJECTIONS

Introduction

Map projections are attempts to portray the surface of the earth or a portion of the earth on a flat surface. Some distortions of conformality, distance, direction, scale, and area always result from this process. Some projections minimize distortions in some of these properties at the expense of maximizing errors in others. Some projection are attempts to only moderately distort all of these properties.

Conformality

When the scale of a map at any point on the map is the same in any direction, the projection is conformal. Meridians (lines of longitude) and parallels (lines of latitude) intersect at right angles. Shape is preserved locally on conformal maps.

Distance

A map is equidistant when it portrays distances from the center of the projection to any other place on the map.

Direction

A map preserves direction when azimuths (angles from a point on a line to another point) are portrayed correctly in all directions.

Scale

Scale is the relationship between a distance portrayed on a map and the same distance on the Earth.

Area

When a map portrays areas over the entire map so that all mapped areas have the same proportional relationship to the areas on the Earth that they represent, the map is an equal-area map.

Properties of map projections

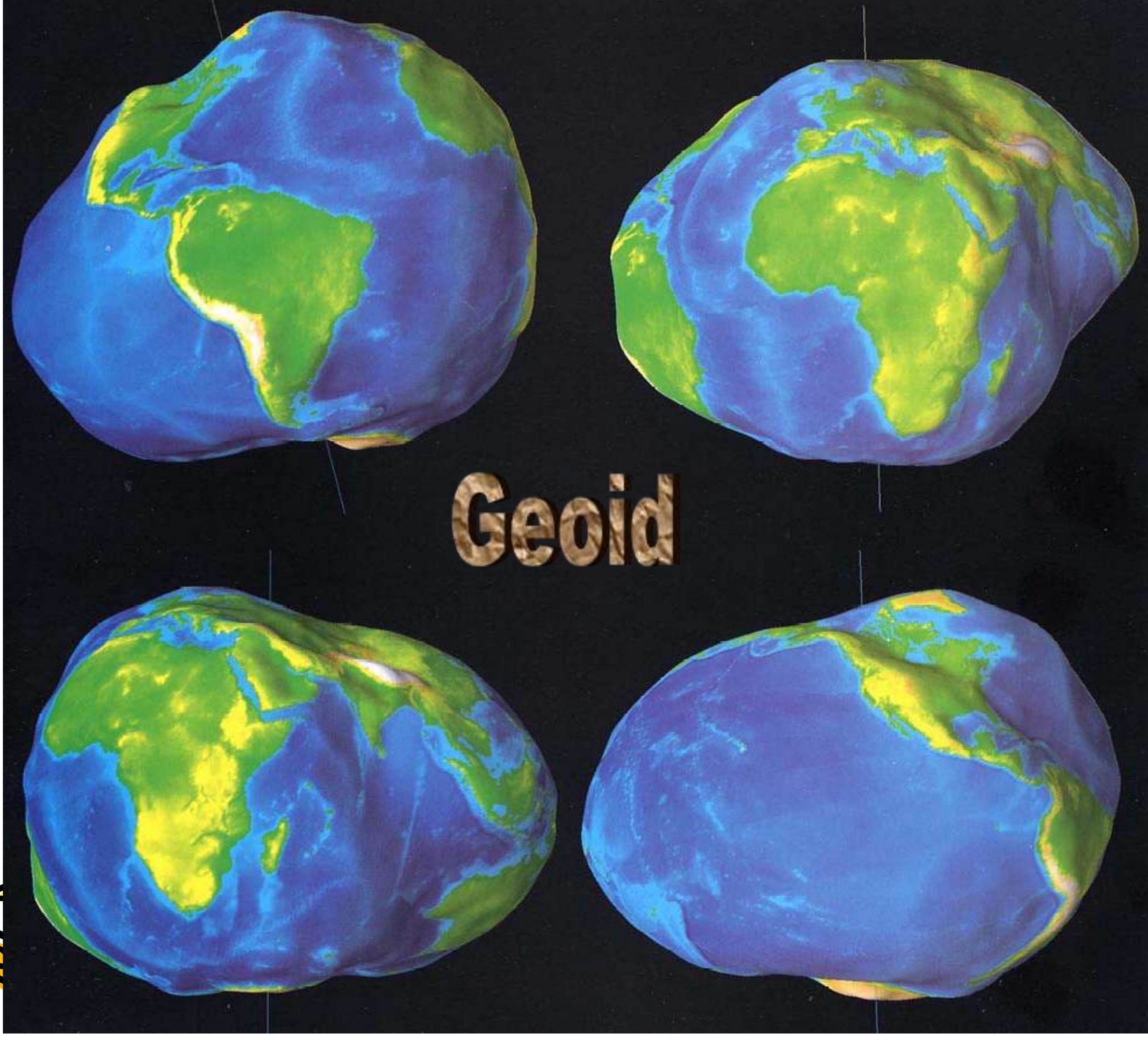
- Conformal projections
  - Preserve local shape → graticule lines on globe are perpendicular
- Equal-area projections
  - Preserve area of features → angle and/or scale may be distorted
- Equidistant projections
  - Preserve distances between certain points; scale is not maintained correctly on an entire map
- True-direction projections
  - True-direction or azimutal projections map great-circles through the center point as straight lines

Basic Definitions

The Shape of the Earth

Since a map is a representation, the original shape of the represented subject must first be defined. An important branch of cartography, **geodesy** studies the Earth shape and how it is related to its surface's features.

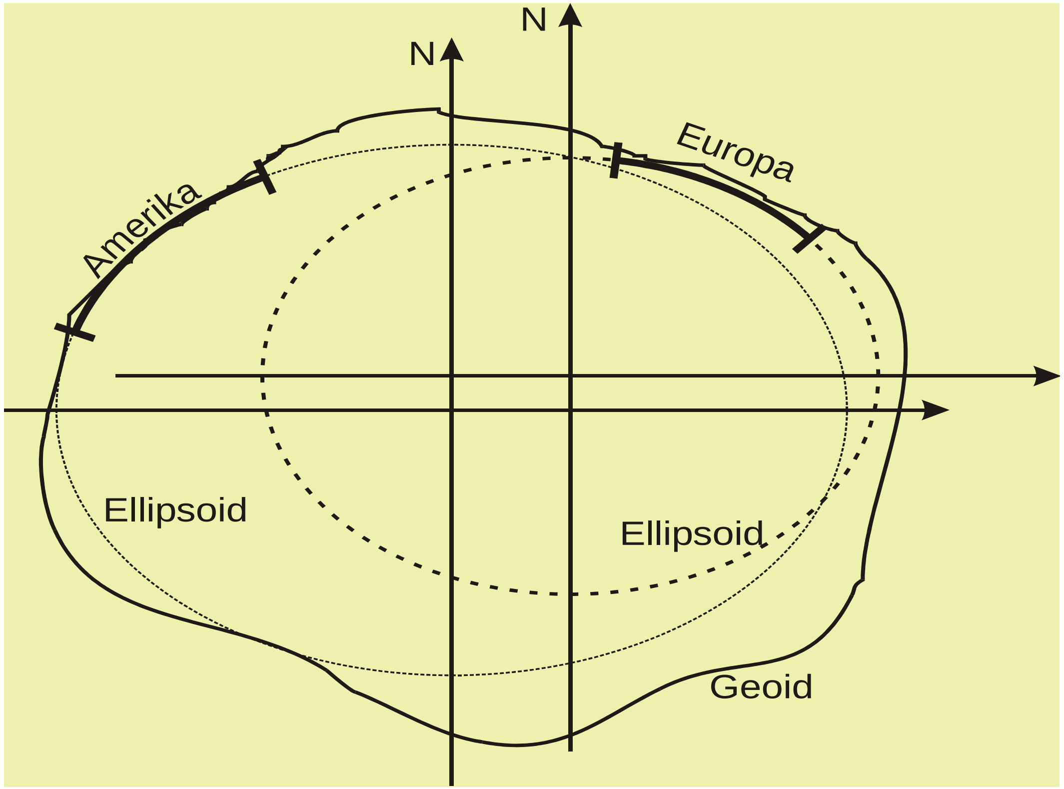
- Geodesy - the shape of the earth and definition of earth datums


Geoid

The geoid: the „true“ shape of the earth

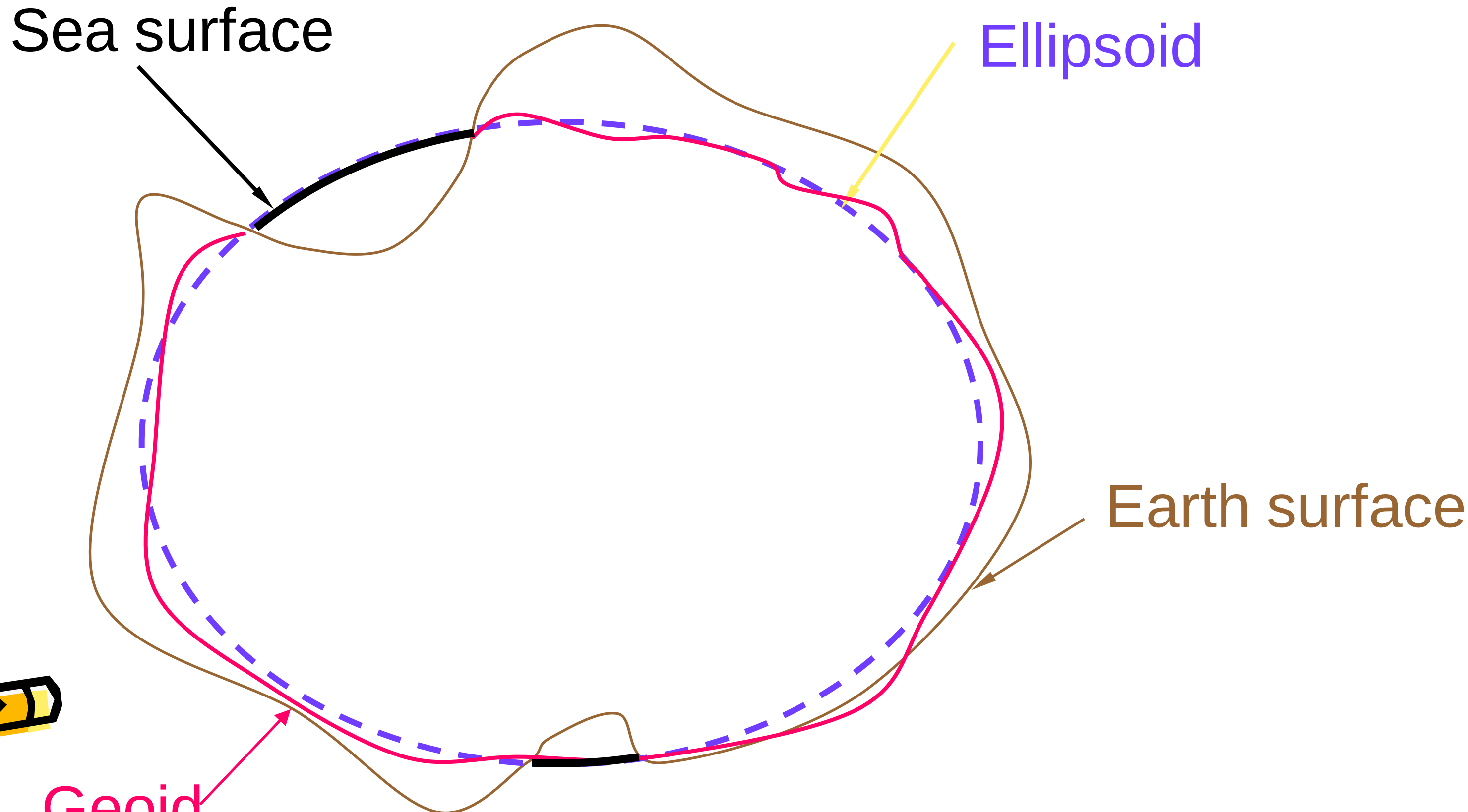
Due to irregular distribution of masses within earth the geoid is irregular

Geoid is only approximated ellipsoid of rotation Local fit of ellipsoids



Representations of the Earth

Mean Sea Level is a surface of constant gravitational potential called the Geoid



Spheres

Like in all space bodies above a certain mass, the Earth's materials aggregated in a spherical shape, which minimizes gravity and potential energy

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spheroids/**oblate ellipsoid**

however, quick rotation around its axis caused a bulging at the middle (Equator) and a flattening at the poles; the resulting shape is called an **spheroid** or **oblate ellipsoid**. The equatorial diameter is nearly 1/300 longer than polar diameter

Ellipse

An ellipse is defined by:

Focal length = ε

Distance (F1, P, F2) is constant for all points on ellipse

When ε = 0, ellipse = circle

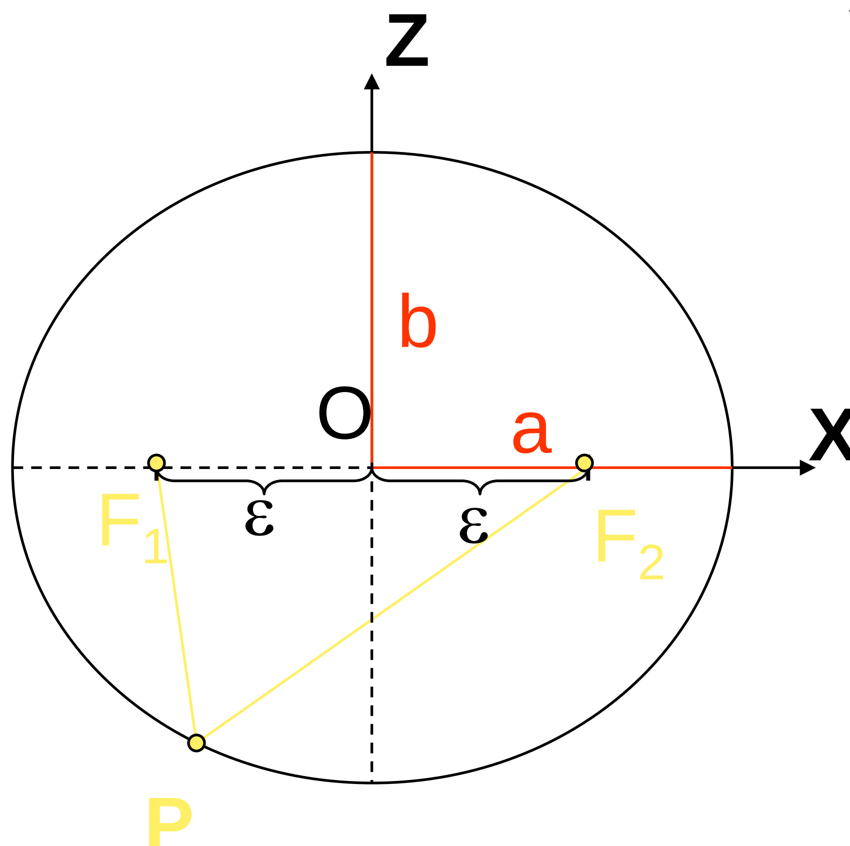
For the earth:

Major axis, a = 6378 km

Minor axis, b = 6357 km

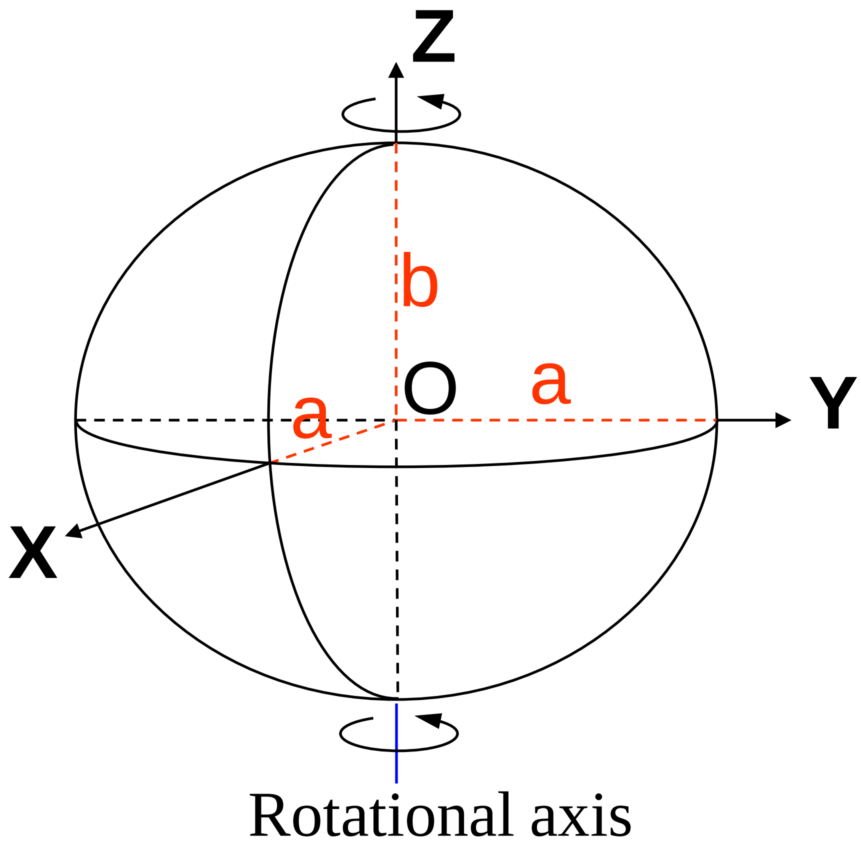
Flattening ratio, f = (a-b)/a

~ 1/300



Ellipsoid or Spheroid

Rotate an ellipse around an axis



Standard Ellipsoids

Ellipsoid	Major axis, a (m)	Minor axis, b (m)	Flattening ratio, f
Clarke (1866)	6,378,206	6,356,584	1/294.98
GRS80	6,378,137	6,356,752	1/298.57

Ref: Snyder, Map Projections, A working manual, USGS Professional Paper 1395, p.12

Shape of the Earth

We think of the earth as a sphere

It is actually a spheroid, slightly larger in radius at the equator than at the poles

The Datum

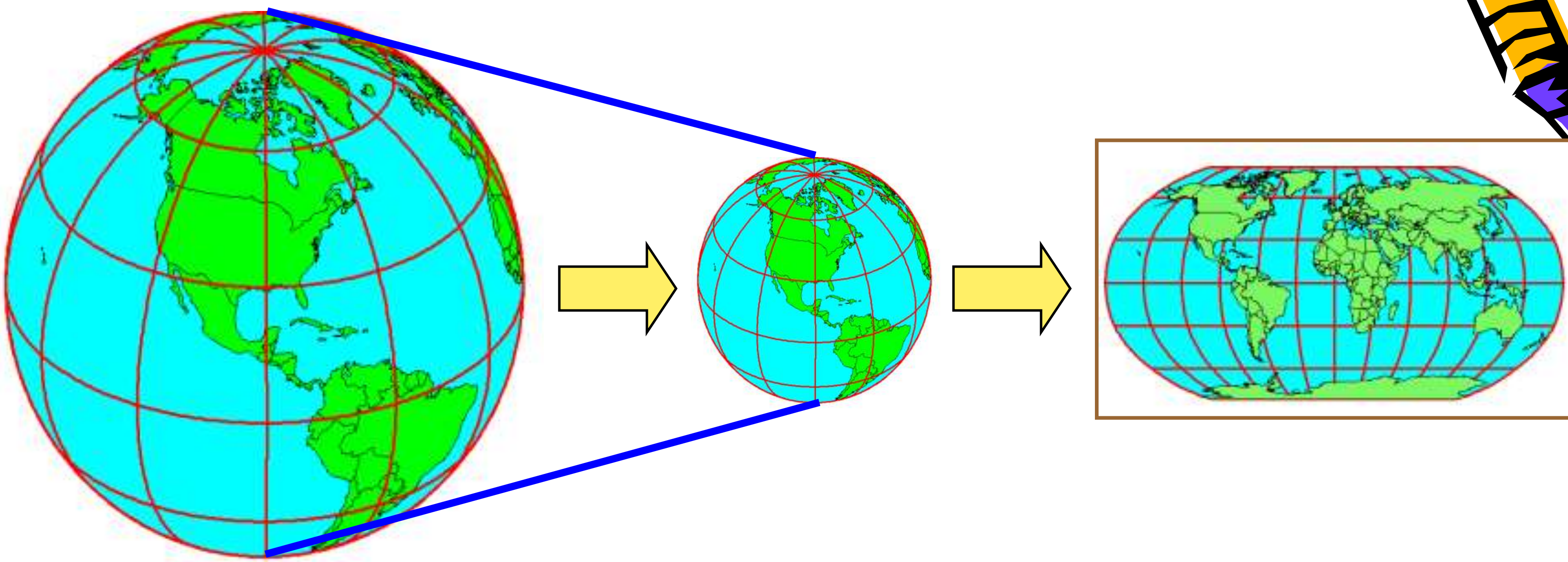
A geodetic **datum** is a set of parameters (including axis lengths and offset from true center of the Earth) defining a reference ellipsoid.

For each mapped region, a different datum can be carefully chosen so that it best matches average sea level, therefore terrain features. Thus, data acquisition for a map involves **surveying**, or measuring heights and distances of reference points as deviations from a specific datum

Horizontal Earth Datums

- An earth datum is defined by an ellipse and an axis of rotation
- NAD27 (North American Datum of 1927) uses the Clarke (1866) ellipsoid on a non geocentric axis of rotation
- NAD83 (NAD,1983) uses the GRS80 ellipsoid on a geocentric axis of rotation
- WGS84 (World Geodetic System of 1984) uses GRS80, almost the same as NAD83

Earth to Globe to Map



Map Scale:

Representative Fraction

$$= \frac{\text{Globe distance}}{\text{Earth distance}}$$

(e.g. 1:24,000)

Map Projection:

Scale Factor

$$= \frac{\text{Map distance}}{\text{Globe distance}}$$

(e.g. 0.9996)

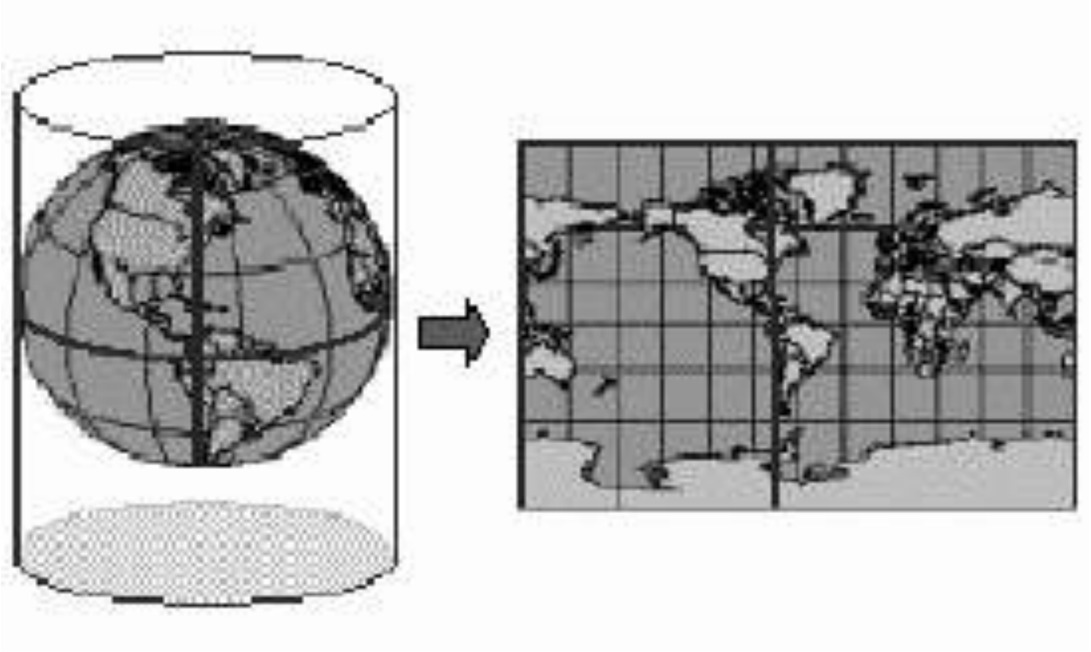
Types of Projections

- Conic (Albers Equal Area, Lambert Conformal Conic) - good for East-West land areas
- Cylindrical (Transverse Mercator) - good for North-South land areas
- Azimuthal (Lambert Azimuthal Equal Area) - good for global views

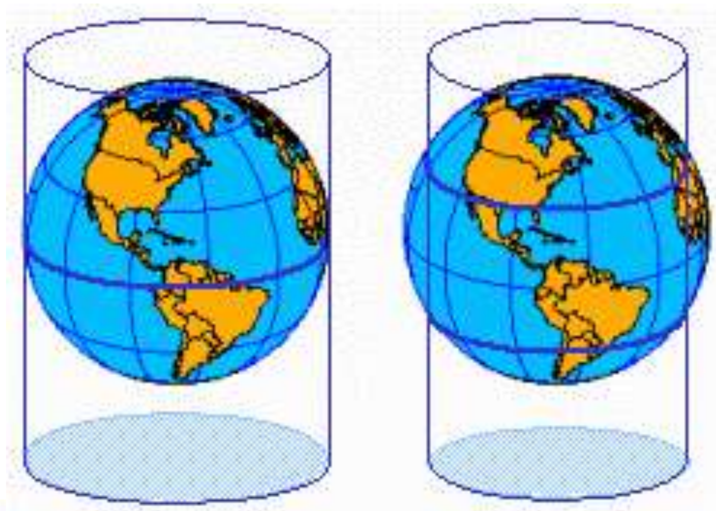
Types of Projections

Cylindrical Projections- created by wrapping a cylinder around a globe and project light from the center of the globe onto the surface of the cylinder.

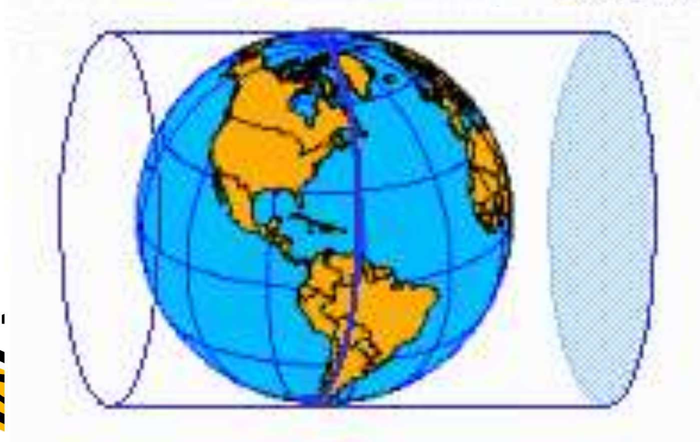
The cylinder is cut along any meridian and is unrolled to produce a flat map. The meridian opposite the cut is called the central meridian (the red line).



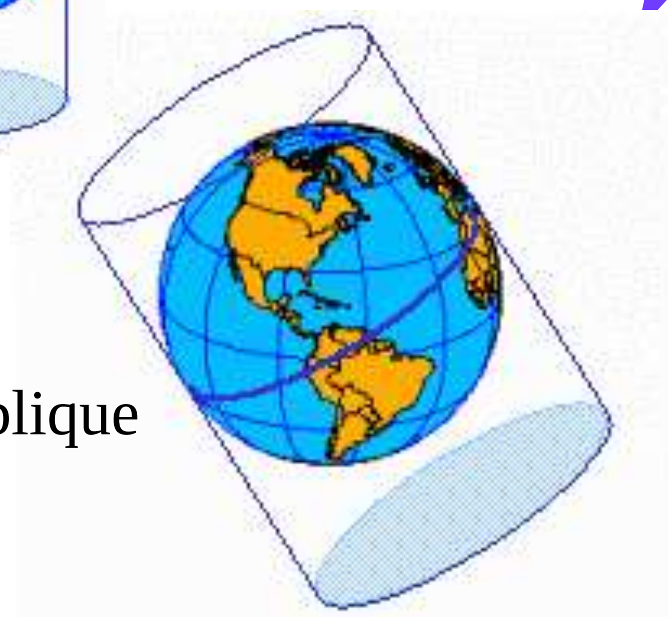
Cylindrical Projections
(Mercator)



Transverse



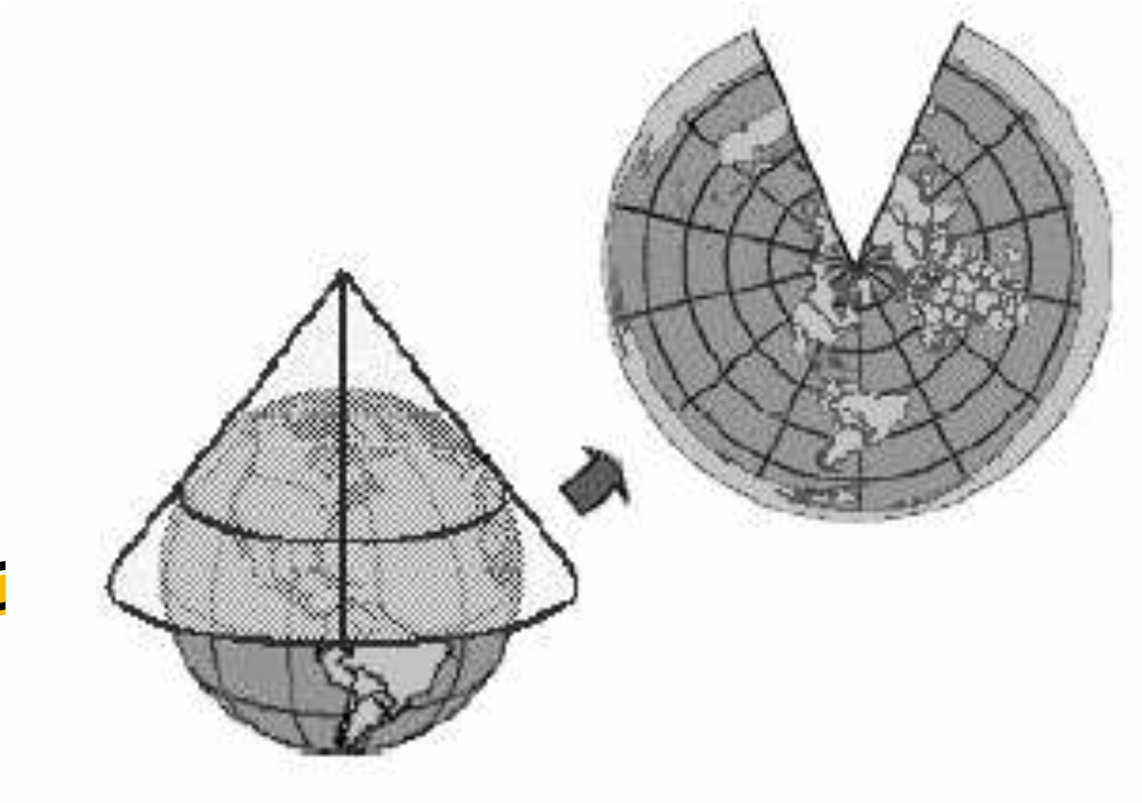
Oblique



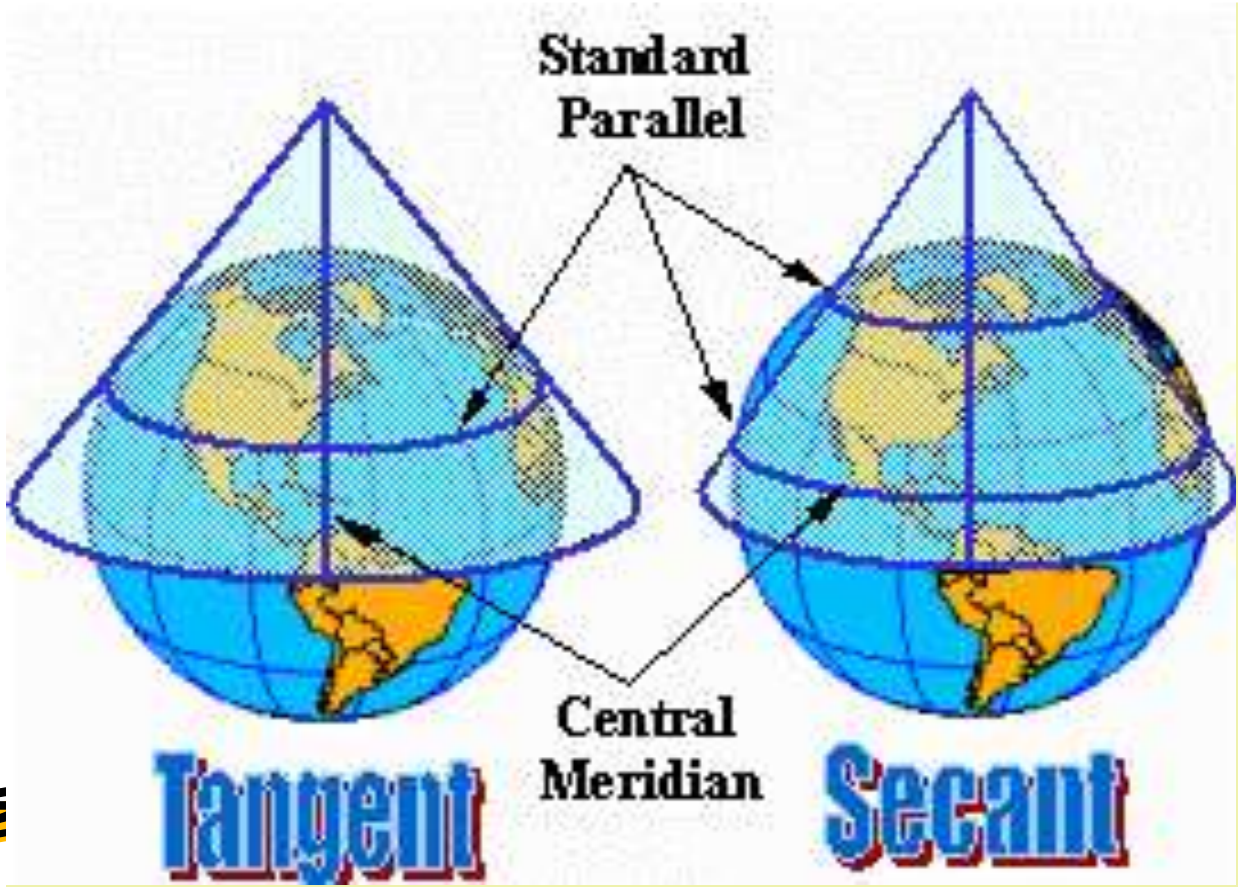
Conic Projection

Conic Projection- created by setting a cone over a globe and projecting light from the center of the globe onto the cone. Simplest cone contact the globe along a single latitude line, a tangent, and is called the standard parallel.

The cone may also intersection at 2 latitudes and these are called the first and second standard parallels.

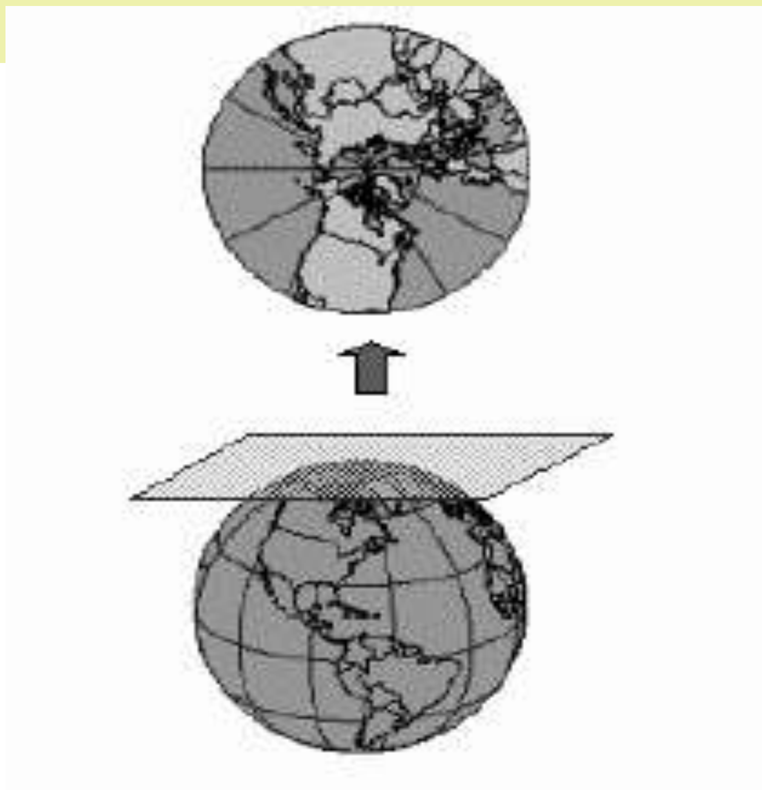


Conic Projections
(Albers, Lambert)

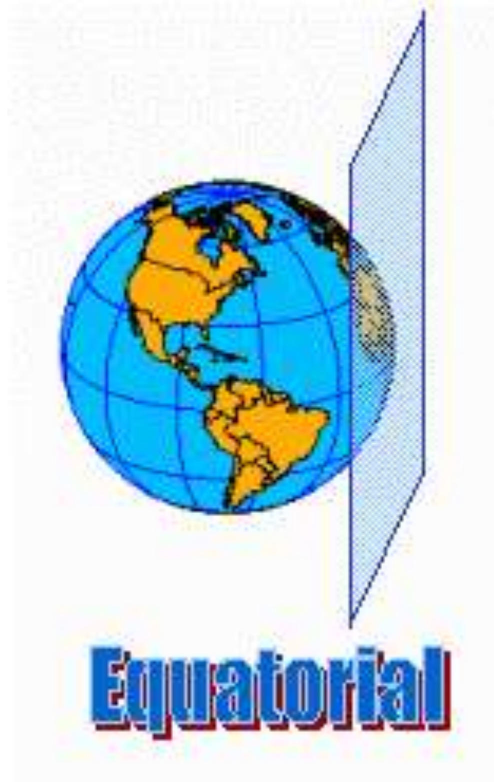


Planar (Azimuthal) Projection

Planar projections- project map data onto a flat surface. Is generally tangent to the globe at one point. North and south poles are the most common point of contact. Area and shape distortion are circular around the point of contact. Therefore planar projections accommodate circular regions better the rectangular areas. Most often used around the poles.



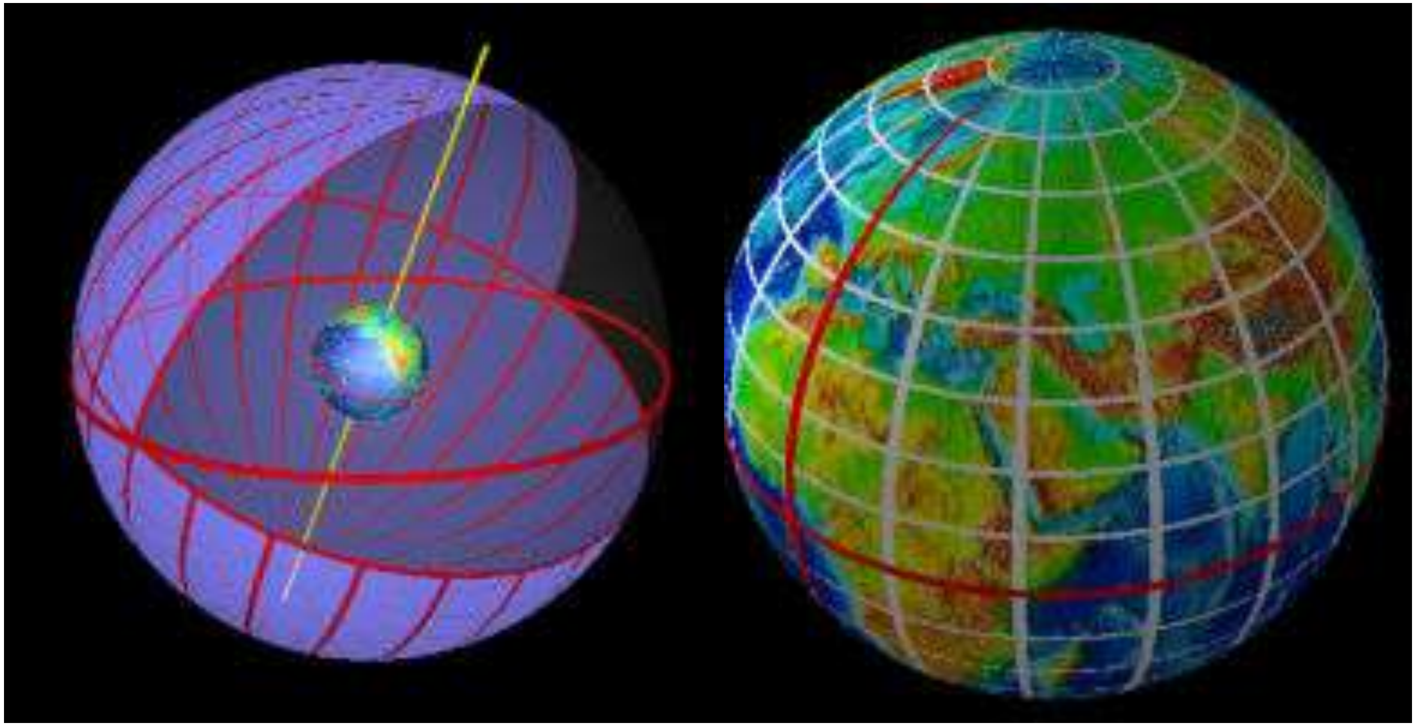
Azimuthal
(Lambert)



Commonly used Projections in

- Conformal projections: Correct angles, correct shape, Mercator, Transverse Mercator, Lambert conformal conic, Polar stereographic
- Equal Area Projections: Correct area, shape distorted Alber's equal area, Lambert equal area, Cylindrical equal area
- Azimuthal: Correct direction Azimuthal equidistant, Gnomanic, Orthographic

COORDINATE SYSTEM



Coordinate Systems

Coordinate derives from *co* meaning jointly, implying that there is more than one, and *ordinatus* which means to order or arrange. Thus a coordinate is one of two or more items used to order or arrange things. A coordinate system is a system which uses two or more coordinates to order or arrange things. Our interest in such things is to order, or arrange, things spatially such that the spatial relationship (and possibly also their relative size and orientation), is appropriately shown relative to other things in our data set.

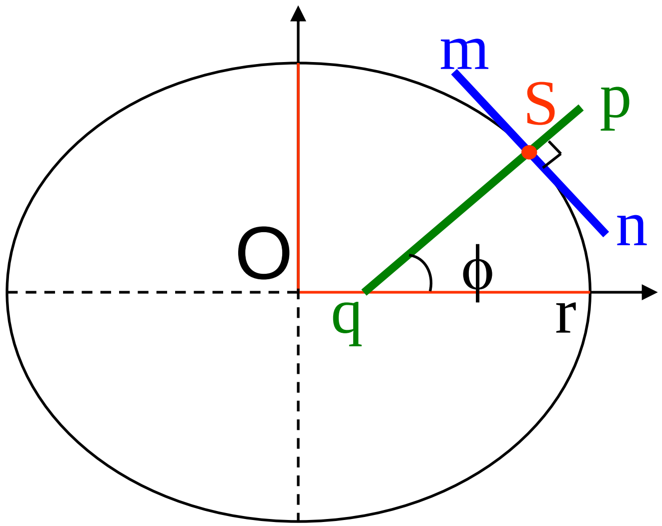
GEOGRAPHICAL COORDINATES

Latitude (abbreviation: Lat.) is the angle at the centre of the coordinate system between any point on the earth's surface and the plane of the equator. Lines joining points of the same latitude are called parallels, and they trace concentric circles on the surface of the earth. Each pole is 90 degrees: the north pole 90° N; the south pole 90° S. The 0° parallel of latitude is designated the equator, an imaginary line that divides the globe into the Northern and Southern Hemispheres.

Longitude (abbreviation: Long.) is the angle east or west, at the centre of the coordinate system, between any point on the earth's surface and the plane of an arbitrary north-south line between the two geographical poles. Lines joining points of the same longitude are called meridians. All meridians are halves of great circles, and are not parallel: by definition they converge at the north and south poles. The line passing through the (former) Royal Observatory, Greenwich (near London in the UK) is the international zero-longitude reference line, the Prime Meridian. The antipodal meridian of Greenwich is both 180°W and 180°E.

By combining these two angles, the horizontal position of any location on Earth can be specified.

Definition of Latitude, ϕ



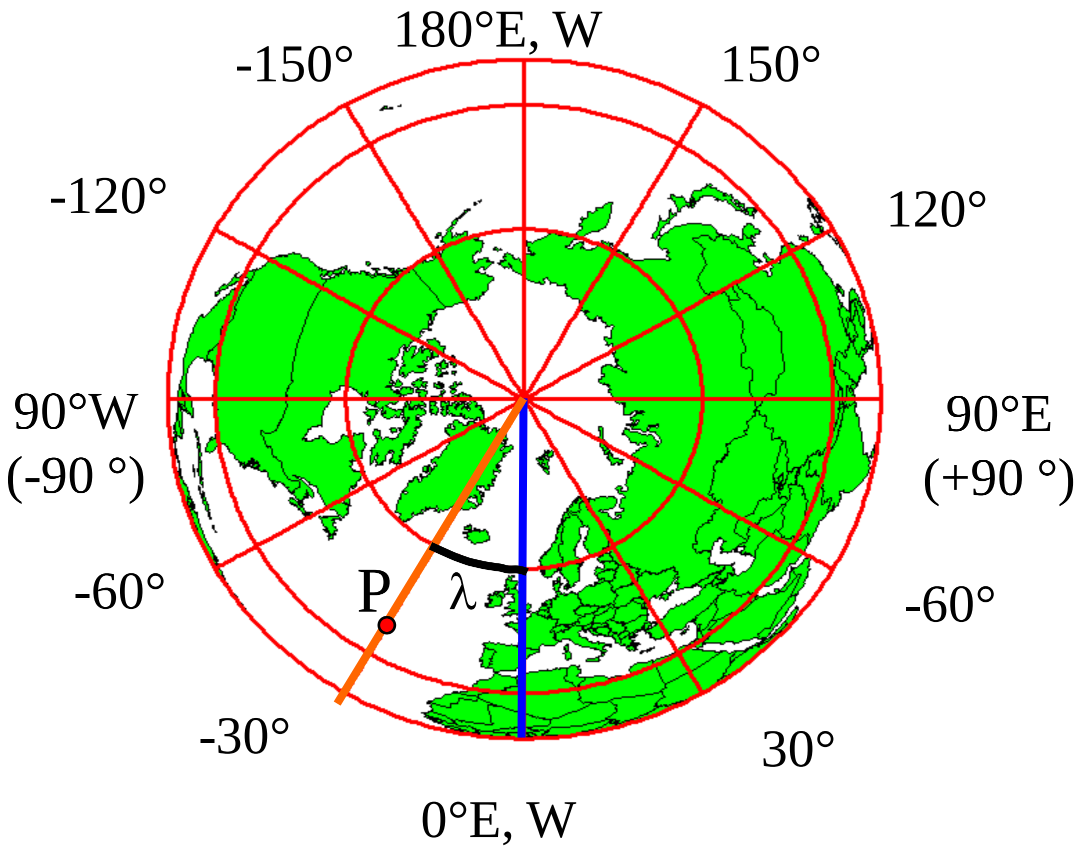
(1) Take a point S on the surface of the ellipsoid and define there the tangent plane, mn

(2) Define the line pq through S and normal to the tangent plane

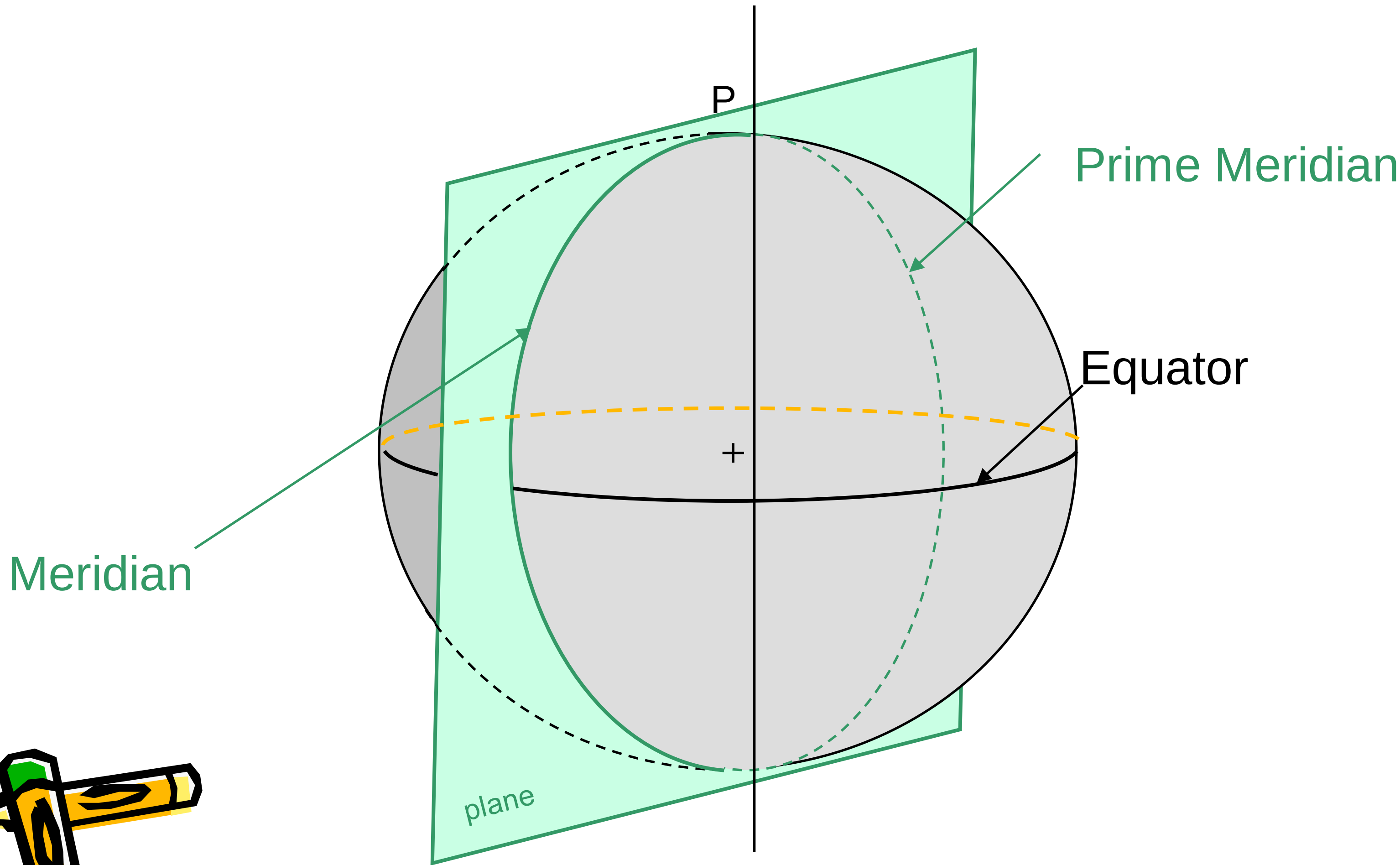
(3) Angle pqr which this line makes with the equatorial plane is the latitude ϕ, of point S

Definition of Longitude, λ

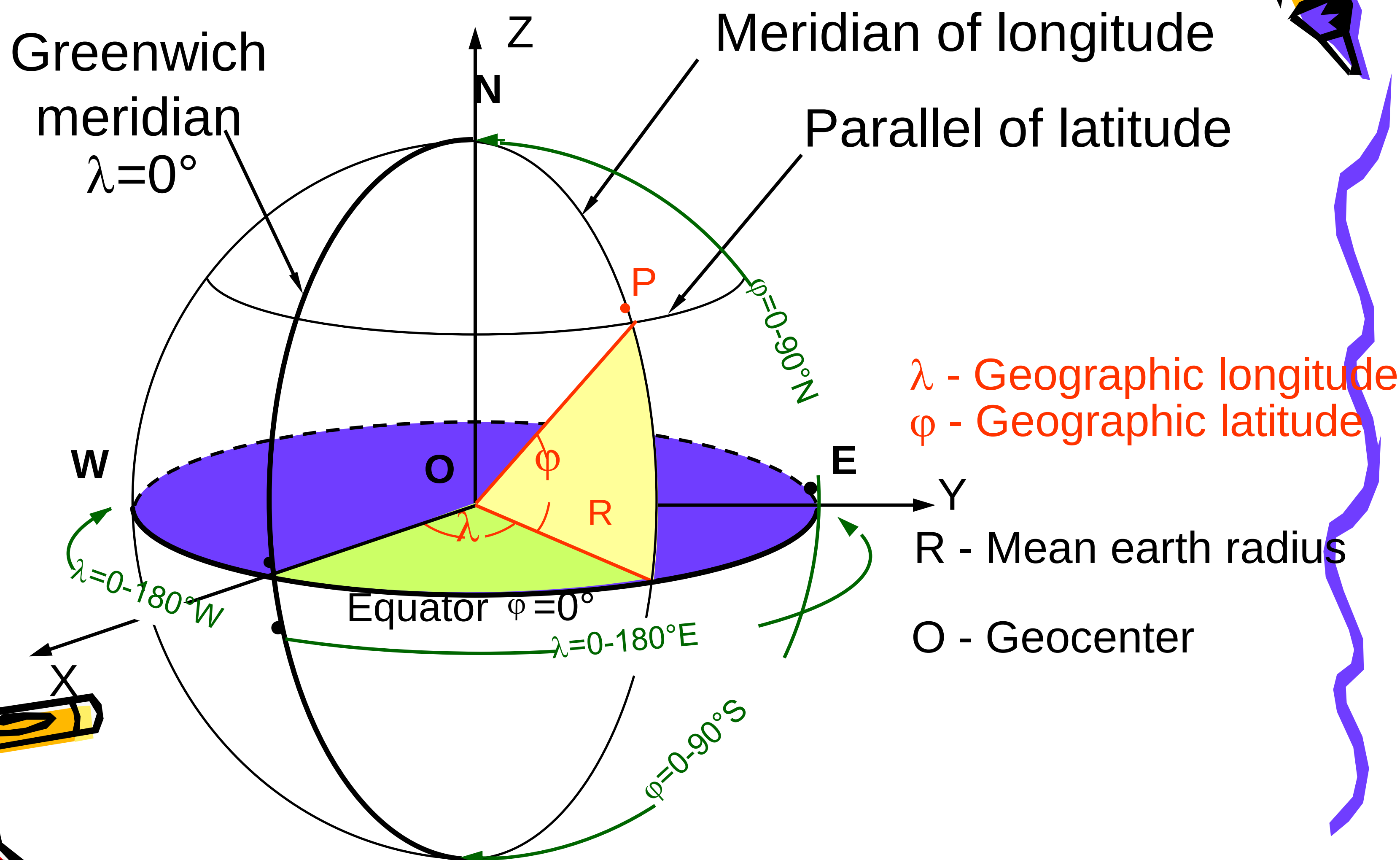
λ = the angle between a cutting plane on the prime meridian and the cutting plane on the meridian through the point, P



Cutting Plane of a Meridian



Latitude and Longitude on a Sphere



PLANE COORDINATE SYSTEM

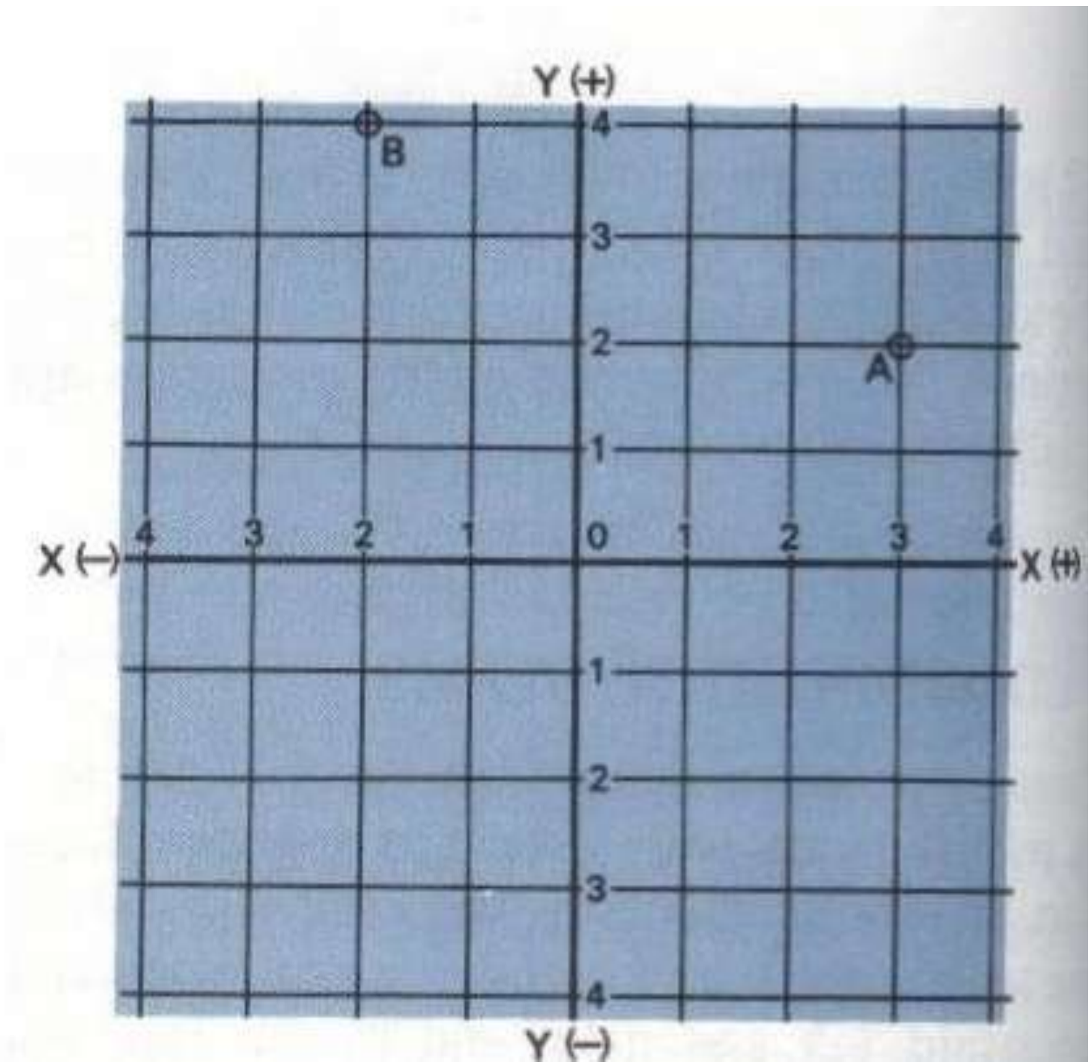
A flat map has only two dimension width (left to right) and length (bottom to top). Transforming the three dimensional earth body into a two-dimensional map is subject of map projections. Here, like in several other cartographic applications, two-dimensional coordinates are needed to describe the location of any point in an unambiguous and unique manner.

Cartesian Coordinates

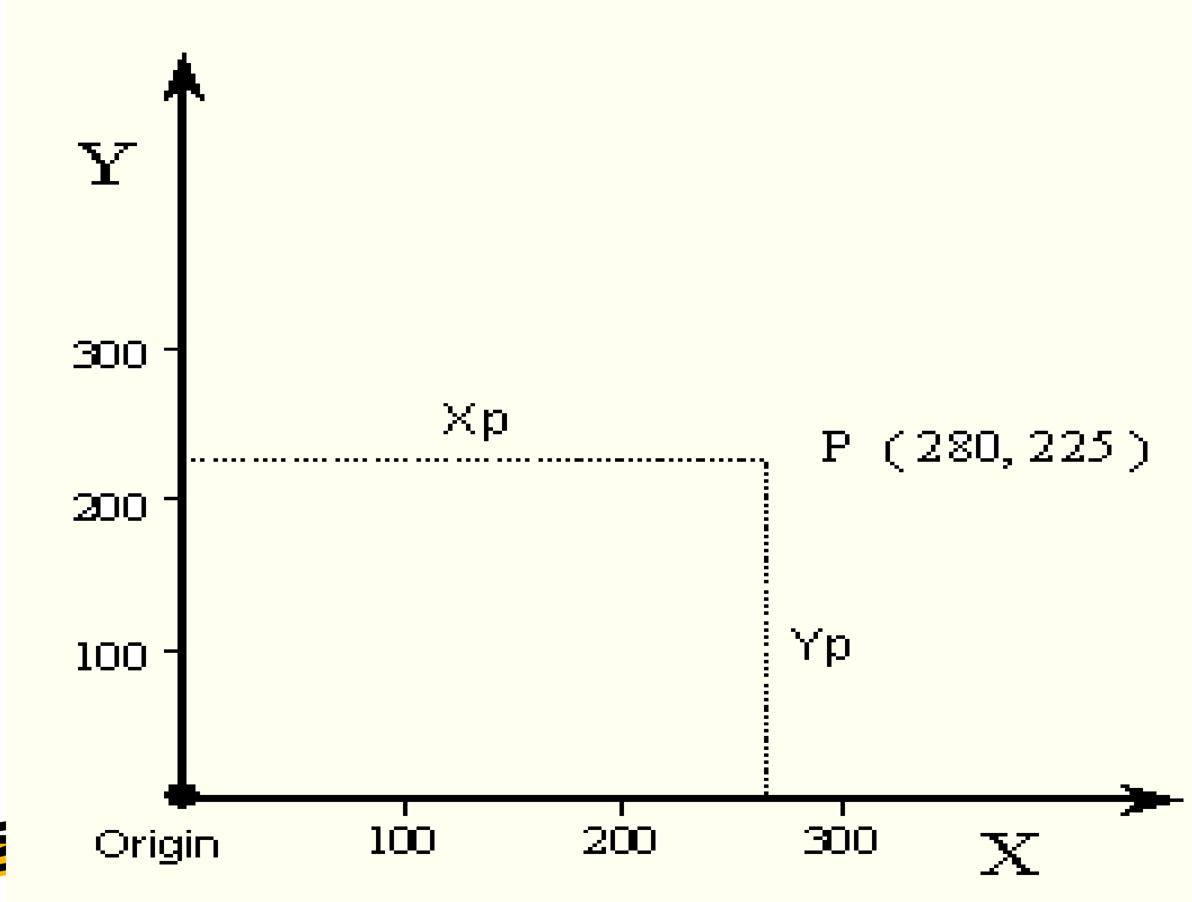
In mathematics, the **Cartesian coordinate system** (also called **rectangular coordinate system**) is used to determine each point uniquely in a plane through two numbers, usually called the *x-coordinate* and the *y-coordinate* of the point. To define the coordinates, two perpendicular directed lines (the *x-axis* or abscissa, and the *y-axis* or ordinate), are specified, as well as the unit length, which is marked off on the two axes .

(Note that the X-axis is sometimes called Easting and the Y-axis Northing).

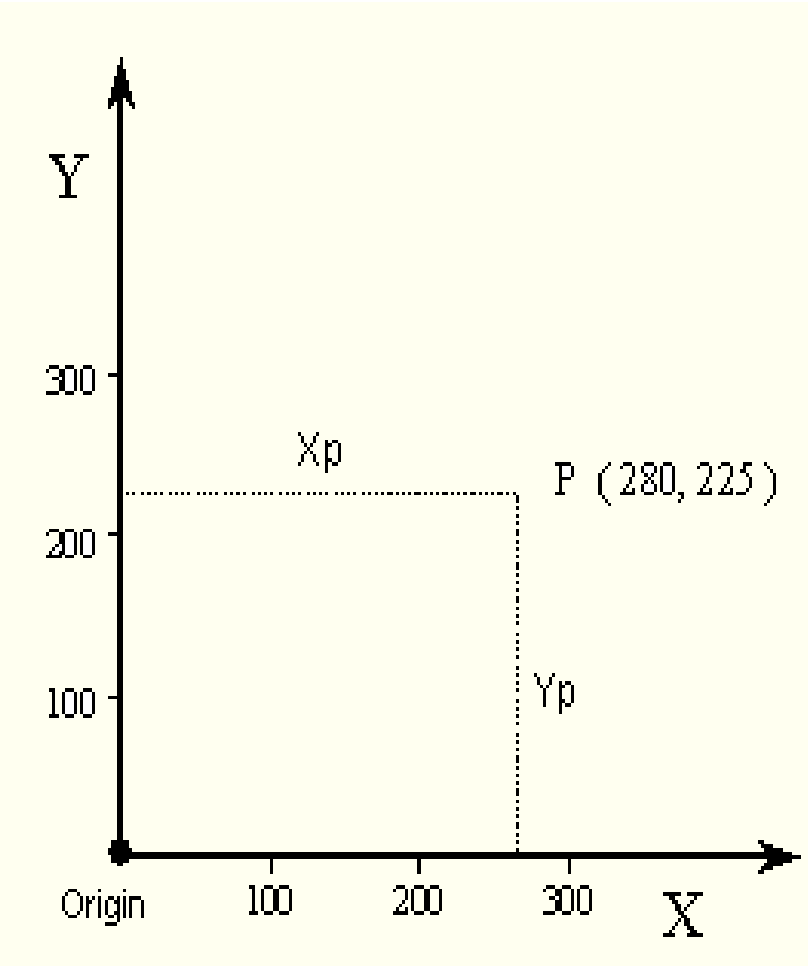
Determination of location on simple Cartesian coordinate system



The intersection of the X- and Y-axis forms the origin. The plane is marked at intervals by equally spaced coordinate lines.



The 2D cartesian coordinate system



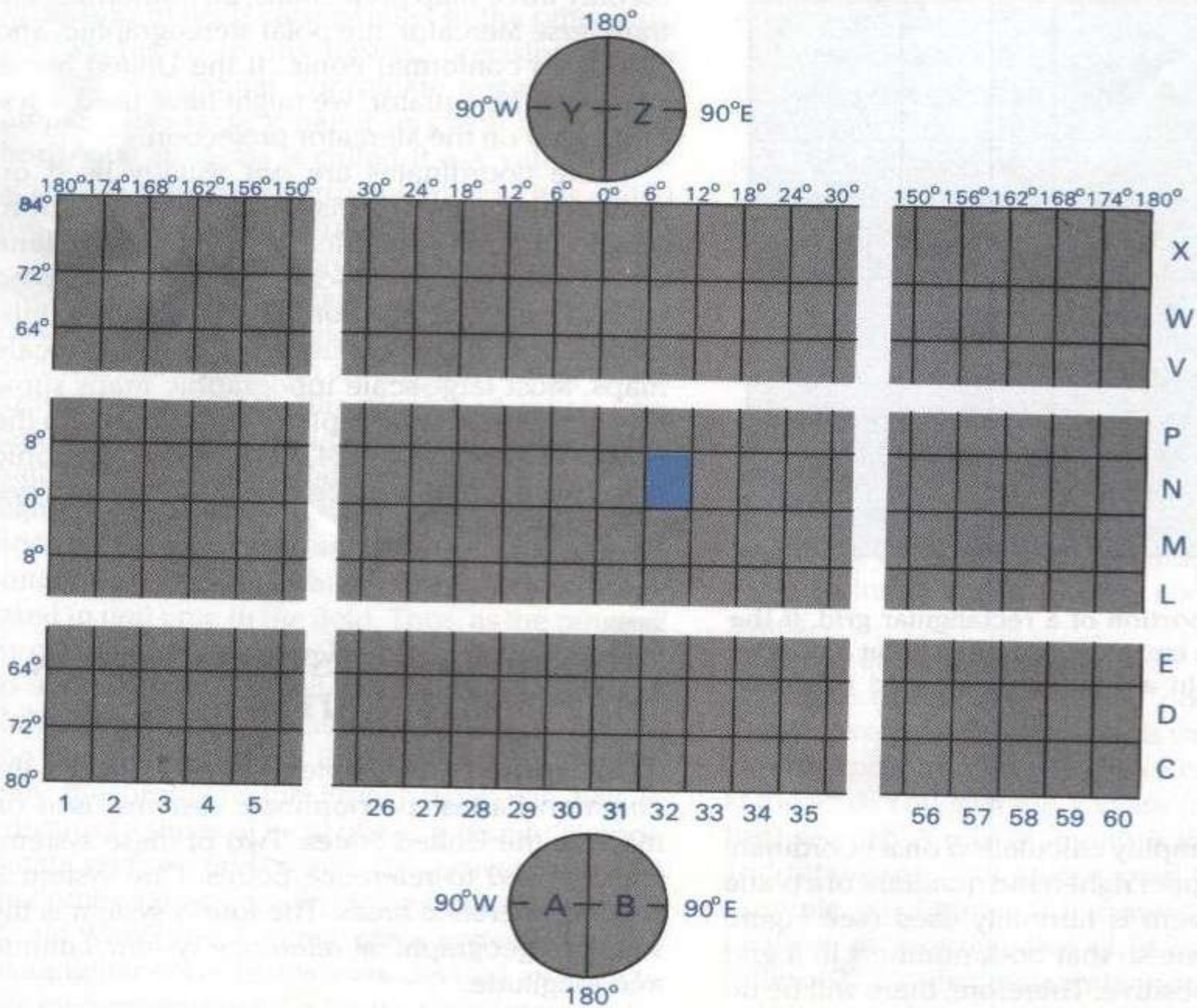
The 2D cartesian coordinate system

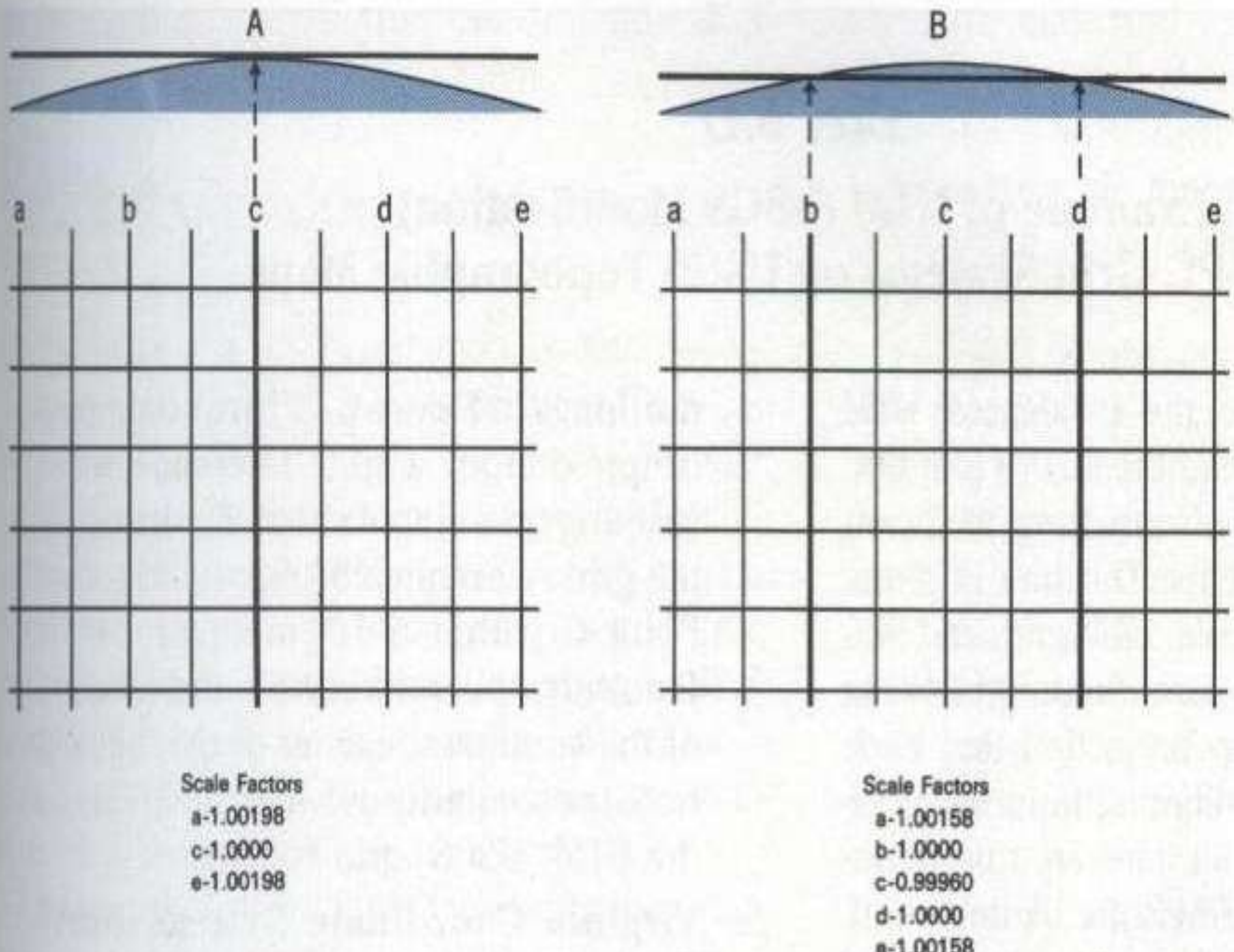
Giving its two numerical coordinates Xp and Yp, one can precisely and objectively specify any location P on the map. Normally, the coordinates Xp= 0 and Yp = 0 are given to the origin. However, sometimes large positive values are added to the origin coordinates. This is to avoid negative values for the X - and Y - coordinates in case the origin of the coordinate system is located inside the area of interest. The point which has then the coordinates Xp= 0 and Yp= 0 is called the **false origin**. Rectangular coordinates are also called cartesian coordinates after Descartes, a French mathematician of the seventeenth century.

Universal Transverse Mercator Coordinate Systen

- The most widely used coordinate system in the world
- Covering 84° N to 80°S
- Based on conformal projection, Transverse Mercator
- Divided in vertical columns called zones that are 6° of longitude apart, starting from 180° W
- These zones are further subdivided in sub zones 8° of latitude apart numbered C to X (omitting I and O)
- Each quadrangle is divided into 100,000 meter zones which give rise up to five digit easting values and five digits northing values
- Overall accuracy in UTM is 2,500

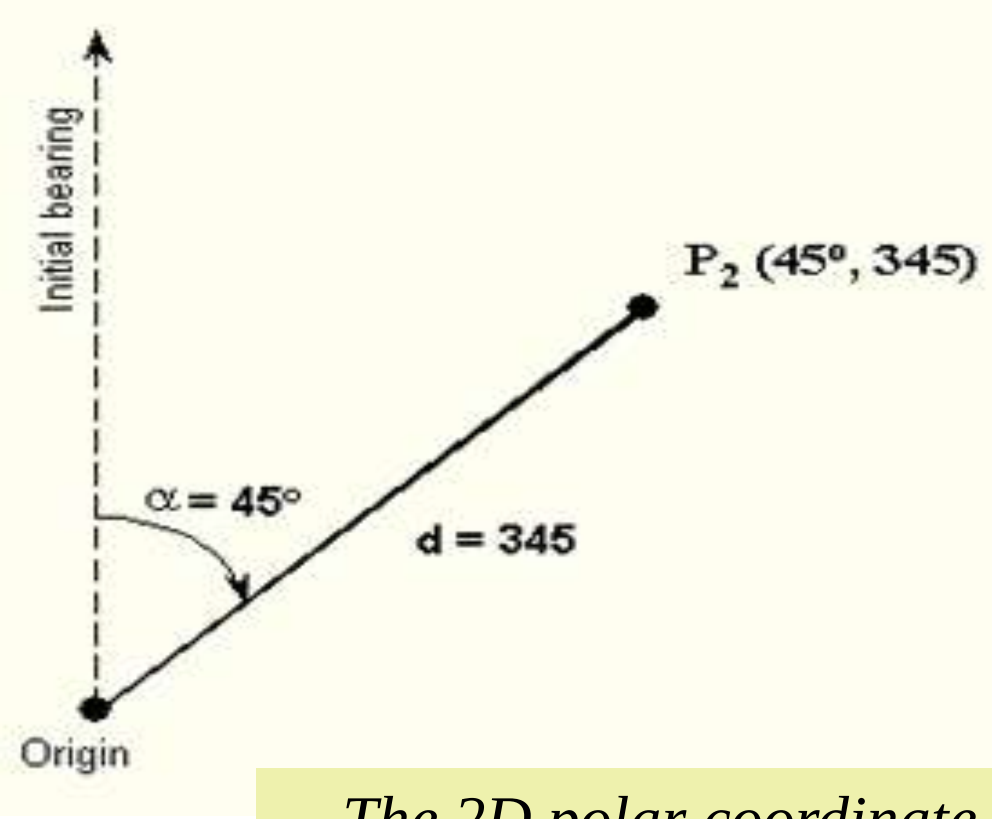
Universal Transverse Mercator Coordinate Grid



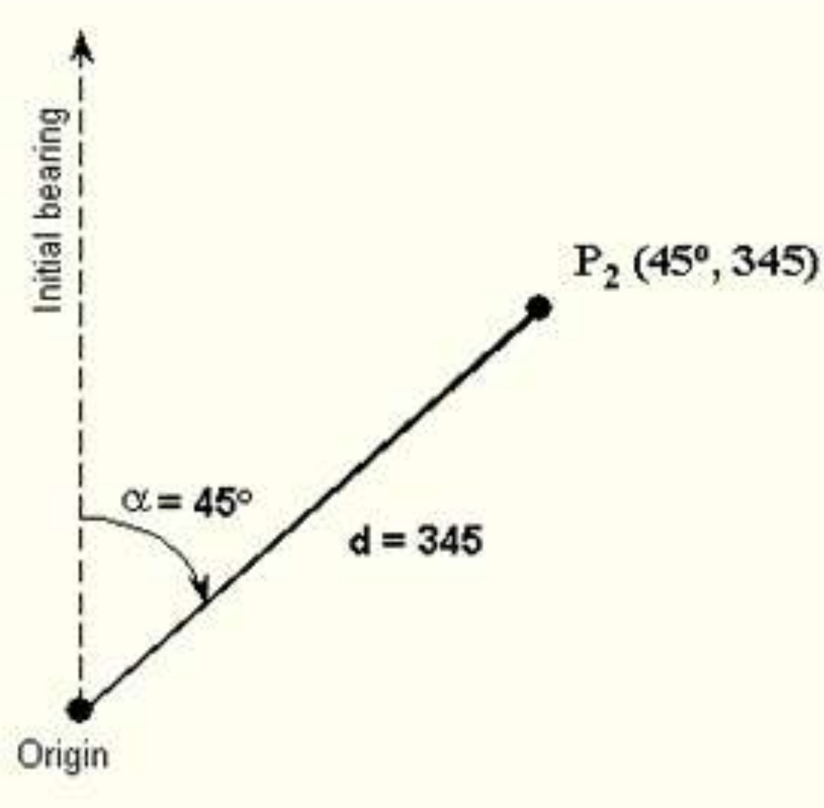

A
B
a
b
c
d
e
a
b
c
d
e
Scale Factors
a-1.00198
c-1.0000
e-1.00198
Scale Factors
a-1.00158
b-1.0000
c-0.99960
d-1.0000
e-1.00158

Polar Coordinates

Another possibility of defining a point in a plane is by polar coordinates. This is the distance d from the origin to the point concerned and the angle a between a fixed (or zero) direction and the direction to the point.



The 2D polar coordinate system



The 2D polar coordinate system

The angle a is called azimuth or bearing and is counted clockwise. It is given in angular units while the distance d is expressed in length units. Bearings are always related to a fixed direction (initial bearing) or a datum line. In principle, this reference line can be chosen freely. However, in practice three different directions are widely in use: *True North, Grid North* and *Magnetic North*. The corresponding bearings are called: true bearing or geodetic bearing, grid bearing and magnetic or compass bearing.