

Chapter 6

The Earth's Graticule and Projections

“... but then I wonder what Latitude or Longitude I've got to?”
(Alice had not the slightest idea what Latitude was, or Longitude
either, but she thought they were nice grand words to say.)

—LEWIS CARROLL, *Alice in
Wonderland* (1865)

THE EARTH'S GRATICULE

The Size and Shape of the Earth

Many aspects of mapmaking would be greatly simplified if the earth were a plane surface. However, the earth is not flat, as was realized early in the history of cartography. Attempts were made even by the early Greeks to represent the actual surface with as little distortion as possible.

The true figure of the earth is not a regular shape like a sphere or an ellipsoid, but a lumpy solid called a *geoid*, which simply means “earth-shaped figure.” As Table 6.1 shows, the polar radius is roughly 13 miles less than the equatorial radius. This does not seem like a great difference (on a 12-inch globe the difference is only 0.019 inches or 0.05 centimeter) but for large-scale maps, such as topographic maps or navigation charts, the difference is significant. In addition to flattening of the poles there are other smaller irregularities.

Geodesists, who deal mathematically with the shape of the earth, must consider actual earth measurements, as must surveyors and cartographers who make topographic maps and GIS specialists who make large-scale city maps and the like. For most thematic mapping, however, we are not concerned with the irregularities of the earth's shape, since we commonly make maps of very small areas or small-scale maps for which geodetic accuracy is not a major issue.

TABLE 6.1. Earth Dimensions

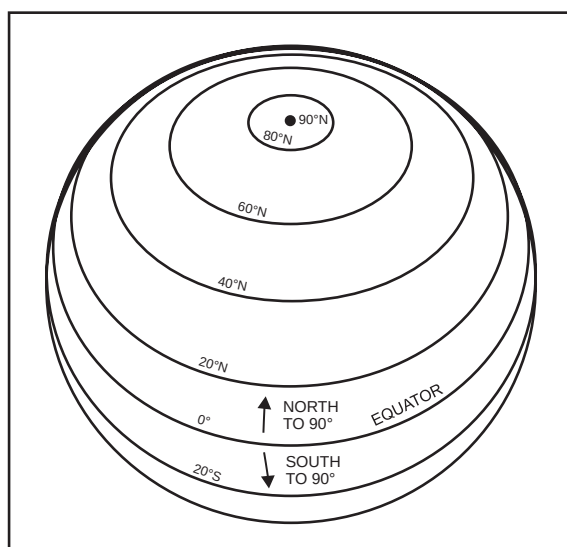
Feature	Kilometers	Statute miles
Equatorial diameter	12,752.401	7,926.677
Polar diameter	12,713.45	7,899.988
Equatorial circumference	40,074.788	24,902
Meridional circumference	40,007.198	24,860

Latitude and Longitude

It is somewhat more difficult to locate points on a spherical surface than on a plane surface since a sphere has no convenient starting and ending points. It is necessary to establish a reference system for the earth in order to locate places with precision. Fortunately, because of its motion, the earth does have two fixed points, the north and south poles, which can be used to establish a reference system. The earth spins on an imaginary axis, the ends of which are the poles, and the north pole always points to the same spot in space.

A *great circle* (one that divides the earth into two equal hemispheres) drawn midway between the poles and at right angles to them is called the *equator* and serves as the starting line for the reference system. Distances from the equator are measured in degrees north or south to the poles. The angular distance north or south of the equator is called *latitude* and is measured from 0° at the equator to 90° north and 90° south at the respective poles (Figure 6.1).

If we connect all points having a given latitude, a *small circle* is formed parallel to the equator at the distance of the chosen latitude. This small circle is called a *parallel*. A parallel is a line on the globe that joins all points having the same angular

**FIGURE 6.1.** Parallels are lines of equal latitude.

distance (latitude) from the equator. *Parallel and latitude are not synonyms; a parallel is a specific line, and latitude is a distance.*

An infinite number of parallels can be drawn, since degrees can be divided into minutes, seconds, and fractions of seconds. This allows us to locate any place on earth precisely with respect to the equator. If the earth were truly spherical, the distance in miles between each degree of latitude would be the same. However, as we have seen, the earth is not a perfect sphere, and thus there is some variation in the length of a degree of latitude. For most small-scale mapping, this variation is too small to be significant.

The system of parallels is only one-half of the earth's reference system. There are 360° along each parallel, and to pinpoint a location, we must also specify where it lies on the parallel. Unfortunately, there is no fixed point or line on the earth comparable to the poles or the equator that can be used as a convenient origin for measurement along the parallels. For many years each country used a true north–south line passing through its capital or some other significant location. Distances were measured from this line in degrees and called *longitude*. When maps of only one country were used there were few problems; but with faster travel around the earth and the use of a variety of maps, this system became cumbersome. Many atlases in the United States during the 19th century contained maps on which the longitude from Washington was printed along one border and the longitude from London along the opposite border to eliminate tedious comparisons and calculations.

In 1884, the International Meridian Conference established the line through the transit instrument at the Royal Observatory at Greenwich, England, as the starting line for east–west measurement; this line is called the *prime meridian*. The angular distance east or west of the prime meridian to some other point, measured from 0° to 180°, is the longitude. If a series of lines is drawn at right angles to the parallels and connecting the poles (by passing planes through the poles), the lines are true north–south lines and are arcs of great circles. These lines are called *meridians*. A meridian is a line that joins all points having the same longitude (Figure 6.2). Note that each meridian is one-half of a great circle. Also note that like parallel and latitude, meridian and longitude are not synonymous. Meridians are lines, longitude is angular distance. The grid formed by parallels and meridians is the *graticule*.

Distance

Although the terms *distance* and *direction* are used frequently in everyday speech, there is confusion about the actual meaning of these terms when referring to the earth's spherical surface.

On a plane, the shortest distance between two points is a straight line, but on the surface of a sphere, the shortest distance between any two points is an arc of a great circle. Thus, if two points are located on the same parallel, the shortest distance between them is not along the parallel (unless that parallel is the equator), but along the great circle joining them. This circle can be found on a globe by stretching a string between the two points.

A convenient unit for measuring distance on a globe is the *nautical mile*. A nautical mile is defined as 1 minute of arc on a great circle of a sphere that has the same surface area as the earth. Given the scale of most globes, this can be taken as simply

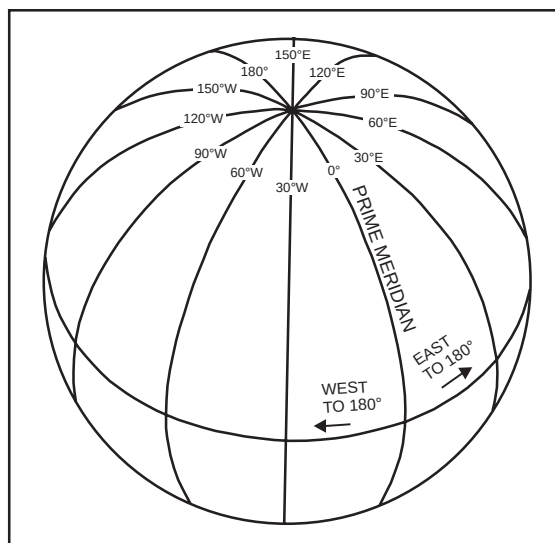


FIGURE 6.2. Meridians are lines of equal longitude.

1 minute of arc on a great circle. We determine the number of minutes separating the two points by comparing the distance to the same distance on the equator of a globe. If it is necessary to have this distance in statute miles or kilometers, it can easily be converted (see Table 5.2).

Direction

Direction is a difficult concept when applied to a sphere. *Direction* is the position of one point on the earth relative to another point. It is usually measured by the angle between a reference line and the shortest line that can be drawn from the point of observation and the point of interest. Since the shortest distance on a sphere is a great circle, then the direction of a point on the earth is the angle between the reference line (a meridian) and an arc of the great circle running between the observer and the point. Direction is stated as *azimuth*. Azimuth is the angle measured clockwise from the reference line and has a value between 0° and 360° (Figure 6.3).

Compass directions such as north, south, east, west, southwest, and so on are commonly used when speaking of direction. A line of constant compass direction, that is, a line that cuts all meridians at the same line, is called a *loxodrome* or *rhumb line*. An aircraft following a constant compass course other than north or south would trace a spiral toward a pole, but would theoretically never reach it. This is a *loxodromic curve* (Figure 6.4).

In this book “loxodrome” or “line of constant compass direction” refers to these directions, and the term “azimuth” is used synonymously with “direction.” It is important to distinguish between these terms because, as we shall see later, some projections show lines of constant compass direction as straight lines, and others show great circles as straight lines. These are mutually exclusive except for the meridians and the equator.

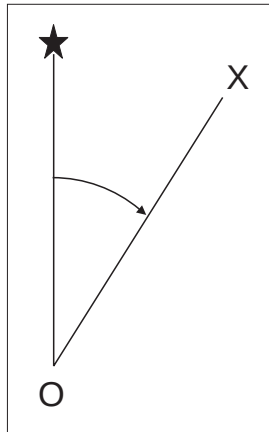


FIGURE 6.3. Azimuth is the angle between a true north–south line and a great circle passing through the observer and the point observed.

Other Grids and Coordinates

For some purposes, grids other than latitude and longitude are used. The primary ones in the United States are the Universal Transverse Mercator Coordinate System, the State Plane Coordinate System, and the Public Land Survey System. USGS topographic maps show all three of these systems in addition to latitude and longitude.

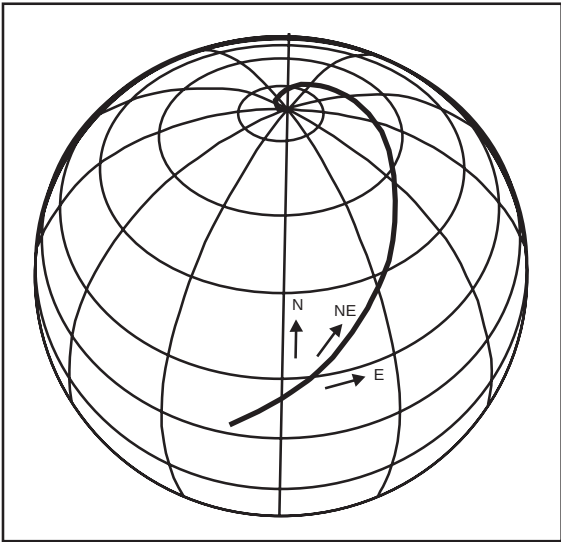


FIGURE 6.4. A loxodromic curve (rhumb line) crosses each meridian at the same angle. It spirals toward the pole.

Universal Transverse Mercator Coordinate System

The Universal Transverse Mercator Coordinate System (UTM), like latitude and longitude, is used to pinpoint locations on the earth. The UTM grid was developed by the U.S. Army in the 1940s and is based on the transverse Mercator projection. The system divides the earth into 60 zones that are 6° of longitude wide. Each zone is centered on a meridian. The zones are numbered from 1 to 60 beginning at 180° and going eastward. Thus, Zone 1 goes from 180° to 174°W and is centered on 177°W (Figure 6.5).

Each longitude zone is divided into 20 latitude zones. Each of these zones is 8° from north to south. Latitude zones begin at 80°S and extend to 84°N . The last zone is extended 4° so that the northernmost lands are covered. The latitude zones are given letters beginning with “C” in the south and continuing to “X” in the north. The letters “I” and “O” are not used because they can be confused with the numbers one and zero. “A,” “B,” “Y,” and “Z” are used for portions of the Antarctic and Arctic areas. The grids formed are referred to by the longitude number and the latitude letter with longitude first. Thus, Los Angeles is in Zone 11S and New York is in Zone 18T.

A place on earth is pinpointed by the longitude zone and an *easting* and *northing* coordinate pair. Easting is the distance of the point from the central meridian of the longitude zone and northing is the distance of the point from the equator. Distances are in meters.

State Plane Coordinate System

The State Plane Coordinate System (SPS or SPCS) shown in Figure 6.6 is widely used by state and local governments and is considered more accurate than the UTM sys-

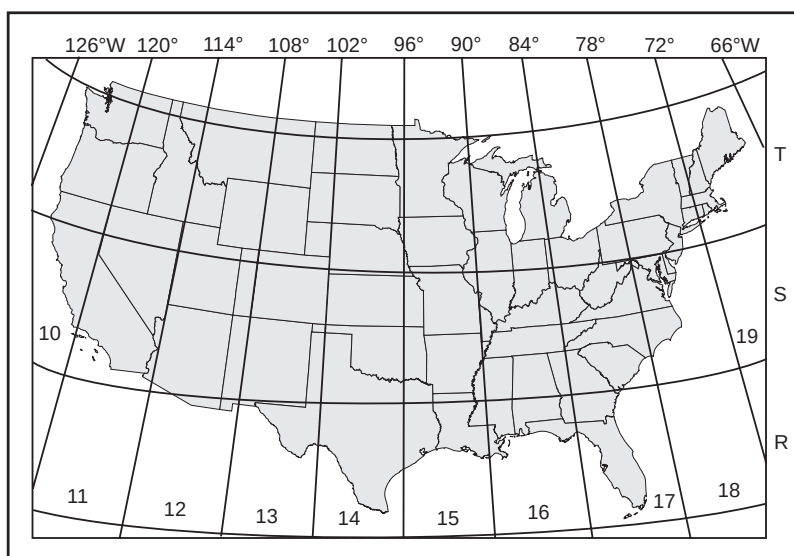


FIGURE 6.5. The UTM zones for the United States.



FIGURE 6.6. State Plane Coordinate System for California.

tem because the zones are smaller. Because the zones are small and because they are based on states the SPCS is not useful for national and regional mapping.

The SPCS, like the UTM, is based on zones, but these generally follow political boundaries so the map of zones appears more irregular. The number of zones in a state depends upon the size of the state; the boundaries within a state follow county lines except in Alaska. The SPCS uses about 120 zones to cover the United States. Like the UTM, eastings and northings are used, which are distances east and west of the origin. The origin is usually 2,000,000 feet west of the zone's central meridian.

U.S. Public Land Survey System

The U.S. Public Land Survey System (PLSS) was first proposed by Thomas Jefferson and implemented shortly after the end of the Revolutionary War. Two ordinances, the Land Ordinance of 1785 and the Northwest Ordinance of 1787, provided for systematic rectangular survey of federal lands so that those lands could be transferred to private citizens. The PLSS is a *cadastral* or property-mapping system. Not all states are covered in the PLSS because it provided for survey before settlement. Thus, the original colonies are not covered, and Texas has its own system (Figure 6.7). The PLSS was initially begun in Ohio, but because the system was not yet fully developed, the surveys in Ohio and Indiana are different from those of other covered states. There are also some areas where other cadastral systems were in use, such as Louisiana, which used the French *arpent* system, or long lots; New England, which used the New England town system; and areas of the Southwest, which used Spanish systems.

The PLSS is based on 37 named principal meridians and base lines, as shown in Figure 6.7 that provide origins. True north–south lines (meridians) and east–west lines are drawn from these origins at 6-mile intervals called “tiers and ranges” (while



FIGURE 6.7. Public Land Survey System. The original 13 colonies and Texas are not covered by the PLSS.

“tiers” is the original term, common usage has become “townships and ranges”). The 36-square-mile areas formed are called *townships* (Figure 6.8). Each township is divided into 36 one-square-mile areas called *sections* that contain 640 acres, and the sections can be further subdivided into quarter sections, eighth sections, and so forth so that any parcel of land has a unique one-line designation. For example, NE1/4, SW1/4, SW1/4, NE1/4, sec. 23, T1SR3W, Mt. Diablo Meridian would describe a 2 1/2-acre piece of land located in the first tier south of the base line, the third range west of the Mt. Diablo principal meridian in the northeast quarter of the southwest quarter of the southwest quarter of the northeast quarter of section 23.

The PLSS is a systematic cadastral survey, but in much of the world unsystematic property surveys, which are also called *metes and bounds* or *indiscriminate location*, have been used. For metes and bounds, property lines and boundary markers are arbitrarily selected and are often natural features such as rocks, rivers, or trees. A property description might begin, “From the granite boulder at the river bank N30°E, 500 yards to the oak tree, then S80°E 150 yards. . . .” These boundaries, unlike the PLSS, were usually drawn after settlement and the lots tend to form a crazy-quilt pattern.

TRANSFORMING THE EARTH’S GRATICULE: MAP PROJECTIONS

A projection is the transformation of the earth’s spherical graticule onto a plane surface. The formal definition is *a systematic and orderly representation of the earth’s grid upon a plane*. Unlike some shapes, such as a cone, a sphere cannot be flattened without some distortion. The projection is a foundation because it governs the positions of points on the map with respect to one another. The projection forms the

framework for the map, and therefore it is necessary to decide which projection will be used early in the planning stages of the map. There are an infinite number of projections possible, and more than 400 projections available, although only a relative few are employed regularly.

The key terms in the definition are “systematic” and “orderly.” One does not create a “projection” simply by peeling the globe or tearing off pieces. The graticule is transformed or projected in a systematic manner onto a flat surface, and the positions of continents and seas then plotted onto the transformed graticule.

The shape of the earth was discussed in the preceding section. Here we will not be involved with the geoid or spheroid, but will consider the earth to be a sphere for ease in understanding. Although for large-scale maps, such as topographic maps, the exact shape of the earth must be taken into account, for most thematic maps the earth can be considered a perfect sphere.

Before analyzing projections, the properties of the globe should be reviewed:

1. All parallels are parallel.
2. Meridians are half great circles and converge at the poles.
3. The meridians are evenly spaced along any parallel.
4. Quadrilaterals formed by the same two parallels and having the same longitudinal dimensions will have the same areas.

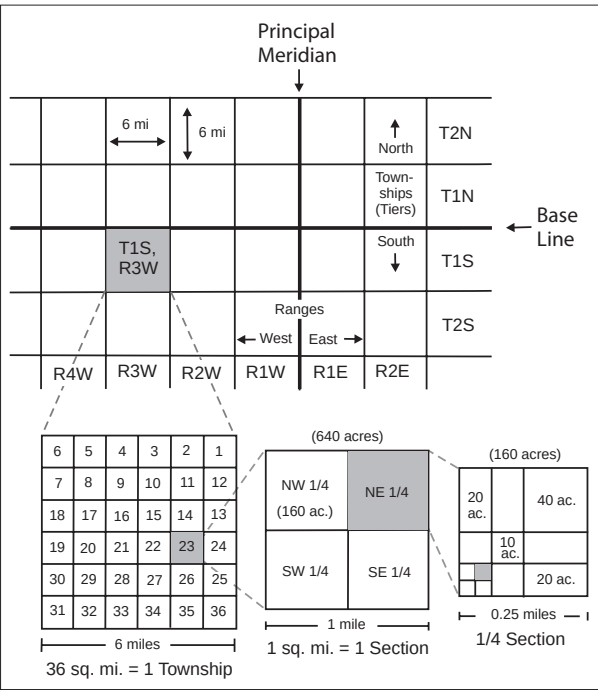


FIGURE 6.8. Townships and sections. Any place within the PLSS can be identified by township and section.

5. Parallels are equally spaced along the meridians (assuming the earth to be a sphere).
6. Area scale is uniform; that is, 1 square inch of the globe in the high latitudes and 1 square inch in the low latitudes covers the same earth area.
7. Distance scale is uniform.

Only a globe can combine all these properties because its shape is virtually the same as the earth's. When the spherical graticule is transformed onto a plane, which radically changes its geometry, unavoidable distortions are introduced. Therefore the only true representation of the earth's surface geometry is a globe (Figure 6.9).

It must not be assumed, however, that because flat maps have distortions they are merely poor substitutes for globes or that globes are without disadvantages. Globes are limited by their practical size. A globe 14 inches in diameter has a scale of 1 inch to 566 miles, hardly feasible for navigation or showing roads. Globes permit only one-half of the earth to be seen at a time. Many thematic maps illustrate global patterns; in such cases, it is desirable to view the entire earth at once. A climate map, for example, is more useful if the entire world pattern can be seen at once and regions compared. Finally, to show all of the thematic maps in even a small atlas would require many globes, which would present storage and handling problems.

Projections can be problem-solving tools and should not be considered negative devices. The distortions of flat maps can be used to advantage. Phenomena that cannot be shown on a globe can be presented on a flat map by exploiting projection properties. For example, the gnomonic projection shows all great circle arcs as straight lines so it can be used for plotting the shortest distance between two points. The Mercator projection shows loxodromes as straight lines and can be used to plot

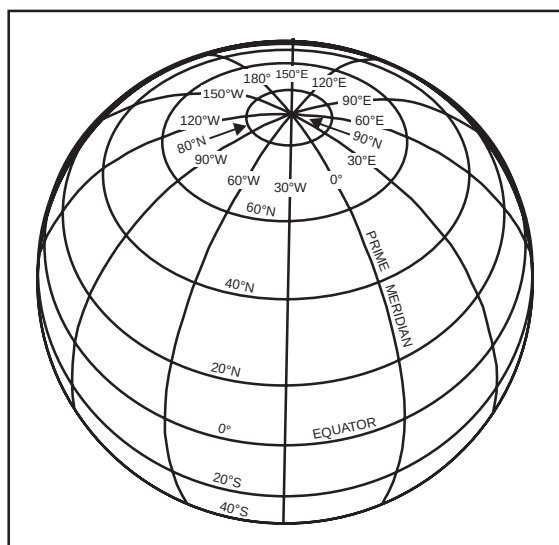


FIGURE 6.9. Earth's grid.

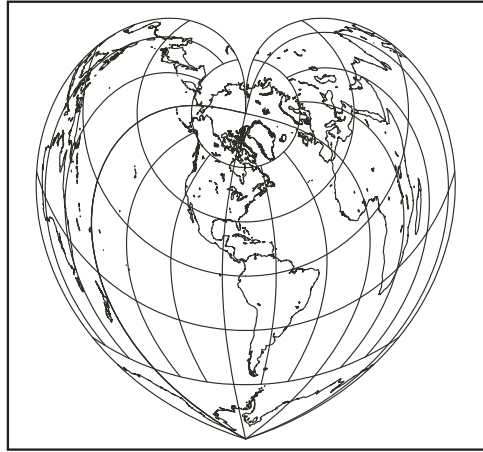


FIGURE 6.10. The cordiform or Stab-Werner projection. “The Cartographer’s Valentine.”

constant compass routes useful for navigators. A projection can also permit the cartographer to zero in on an area and present it in large scale.

There is no single best projection, although sometimes claims are made for new projections that state they are better than any previously constructed projection. This simply is not true. All projections have distortions, and a new projection merely has distortions that are different from those of previously used projections. One cannot even say there is a best projection for a particular use. From the infinite projections possible, there are usually several that could be used for any mapping project, although if enough conditions are specified, the choice can be limited.

While there are an unlimited number of projections and variations on projections possible, many of those already devised are not in common use but remain cartographic curiosities (Figure 6.10). Only about 25 or 30 projections and their variations are widely used (see Appendix A).

The discussion that follows is a simplified and nonmathematical description of projection concepts. Several excellent sources are listed in the Bibliography for those who want a more rigorous treatment.

Classification of Projections

Many attempts have been made to classify projections. Unfortunately, it is not possible to devise mutually exclusive categories since there is always some overlap. The most common classifications are based on *projection properties* and *projection surfaces*.

Projection Properties

It is desirable to preserve some of the geometric properties of the earth’s grid when creating or using map projections. These basic properties and the projection types that preserve them are as follows:

1. *Equivalence of area.* Maps that preserve area scale are called *equal-area* or *equivalent* projections.
2. *Preservation of angles or of shape of small areas.* Projections that have this property are called *conformal* or *orthomorphic* projections.
3. *Linear scale.* Projections that preserve the linear scale for some part of the map are called *equidistant* projections.
4. *Direction, specifically azimuths.* These projections are called *azimuthals* or *zenithals*.

There are various other properties, such as showing great circles as straight lines and the like, but these have no specific category. A last category is a *compromise* group that has no special properties, but presents a good general appearance that is not terribly distorted in any of the properties.

EQUIVALENT PROJECTIONS

A uniform area scale is maintained on equivalent or equal-area projections. Equivalence is obtained by matching stretching with compression. That is, if there is stretching in one dimension, there must be equal compression in the orthogonal (at right angles) dimension. To do this, angles may be distorted, which means that shape is sacrificed. The shapes in Figure 6.11 all have the same area. It is possible to maintain equivalence throughout the projection.

CONFORMAL PROJECTIONS

These are also called *orthomorphic* projections. Often conformal projections are incorrectly described as true-shape projections, but the shape quality is limited. Conformal projections preserve angles with infinitely short sides; therefore, only small features, such as a bay or peninsula, retain correct shape; larger areas, such as countries or continents, are distorted in overall configuration.

Conformality is achieved by meeting two conditions: (1) parallels and meridians must cross at right angles, and (2) scale must be the same in all directions about a



FIGURE 6.11. These shapes each have the same area.



FIGURE 6.12. While the figures in each column have the same shapes, their areas are different.

point. That is, if there is stretching in the longitudinal dimension, it must be matched with an equal amount of stretching in the latitudinal dimension (Figure 6.12). As a result, angles are preserved at the expense of a severely distorted *areal* scale, and squares of 100 square miles in different parts of the globe, while remaining square, will have different apparent sizes on a conformal projection. Figure 6.13 shows a conformal world map compared to an equal-area map. Note the size of Greenland on these two maps. Compare the shape and size to that found on a globe.

Because of the conflicting requirements of equal-area and conformal projections, it is not possible to preserve both properties on a flat map; *it is impossible to design an equal-area conformal projection*. These properties can be achieved simultaneously only on a globe.

EQUIDISTANT PROJECTIONS

A map is called equidistant if distances are shown correctly. Equidistance is not attainable over the entire map; the distance scale of a map is correct only along certain lines or from specific points.

AZIMUTHAL PROJECTIONS

Projections that show azimuths correctly are called *azimuthal* or *zenithal* projections. Unlike conformality and equivalence, this property cannot exist everywhere on the map. *Azimuth is correct only from a single point, the center*; it is not possible to measure the azimuth between any other points on the map. A map that shows constant compass direction is *not* an azimuthal map.

COMPROMISE PROJECTIONS

These are also called *minimum error projections*, a somewhat misleading term. These projections have no particular property except appearance. These are not conformal, but shapes may not be terribly distorted; they are not equal area, but areas may not be

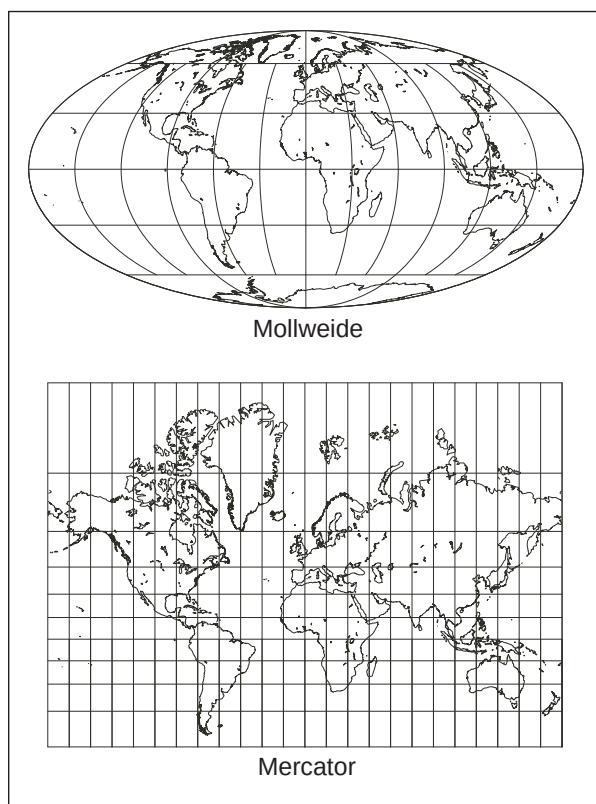


FIGURE 6.13. The Mollweide projection is equal area and the Mercator is conformal. Compare the size of Greenland and South America on the two projections.

poorly represented (Figure 6.14). This is a very useful group of projections for much thematic map work.

Projection Surface

A second common way to classify projections is by the projection surface. Surfaces that can be cut and flattened without distortion or tearing are called *developable surfaces*. The sphere is not a developable surface; it cannot be flattened without distortion or tearing. If, however, the graticule is transformed onto a surface that is developable, that surface can be flattened without any additional distortion (Figure 6.15). A cone can be placed on a globe, the graticule projected onto it, and the cone then unrolled into a plane. The cylinder and the plane may also be used as projection surfaces; the cylinder can be flattened and the plane is already flat. The cylinder and plane may be thought of as extreme cases of a cone. A cone that touches the equator and has therefore an infinitely high apex is a cylinder, and as cones are placed on higher and higher parallels, they approach the plane.

Projection, in theory, is a two-stage process. First, an imaginary globe is created at the intended scale. The imaginary globe is called the *generating globe* or *reference*

globe. The scale of the map projection is called the *defined scale* or the *nominal scale* and is the same as that of the generating globe. The second stage is to project the globe onto a plane.

If we imagine one of the developable forms placed on a transparent reference globe with a light source inside, we can then visualize the earth's graticule being projected onto the developable surface. The name of each group of projections is taken from the surface upon which the map is projected. Consequently, we have cylindrical, conic, and plane projections. A final group of projections is made up of those that cannot in any way be imagined as projected onto one of these surfaces. Various names are given to these last, the most common being *mathematically devised* or *conventional projections*.

Of course, projections are not normally created by a light source and a globe; this would be done only for demonstration or teaching purposes. They are created mathematically and drawn by a computer or, in the past, manually constructed geometrically or from tables (Figure 6.16). Only a limited number of projections can actually be projected by light or by geometric projection (these are called *perspective projections*); but if a projection has the general appearance characteristics of a cylindrical projection, for example, it is placed in this class.

Deformation

As we have seen, all projections have deformations. The larger the area represented, the more significant those distortions become. For example, for a map showing a very small area, such as that of a 1:24,000 topographic map or a city street map, angular deformation, scale differences, and area distortion are negligible. However, if one tries to join topographic maps to cover a larger area, one quickly realizes that there are gaps between the sheets; joining all margins produces a curved surface. If the

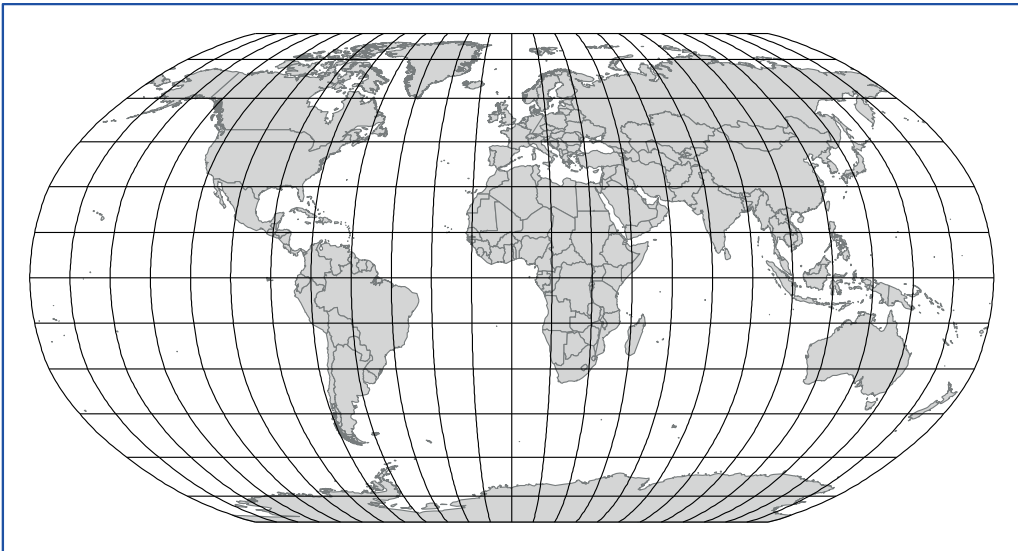


FIGURE 6.14. The Robinson projection, created in 1963, is a compromise projection.

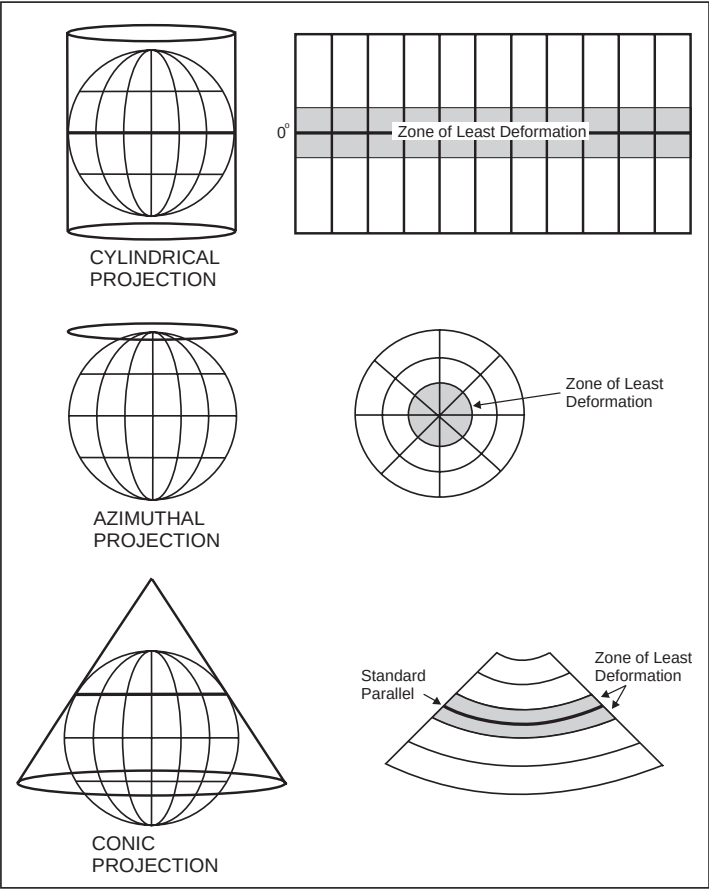


FIGURE 6.15. Developable surfaces and zones of best representation.

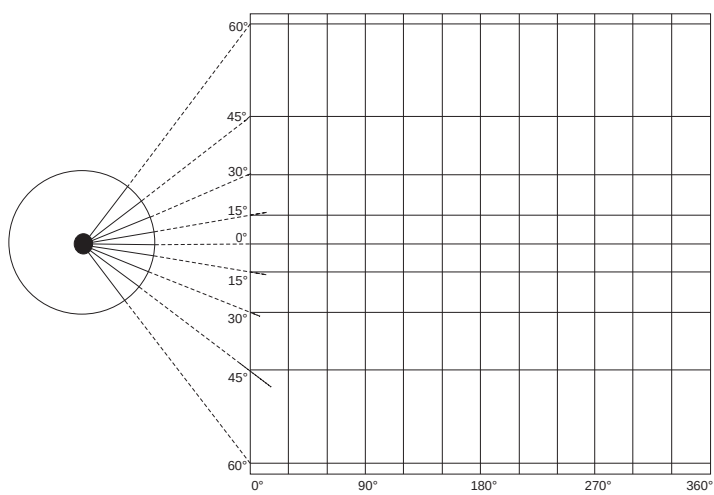


FIGURE 6.16. A simple cylindrical projection can be created geometrically.

entire earth is represented on a flat map, the distortions become obvious and troublesome. Since many thematic maps are of countries or the entire earth, the selection of a projection becomes of paramount importance. The cartographer must choose the projection with the most advantages for the problem at hand and one for which the distortions are least intrusive.

There are several ways of analyzing projection distortions. Tissot's indicatrix, which permits quantification of distortion, is frequently used. It is also possible to draw *isoanamorphic lines* (lines of equal distortion) on a projection to show distortions graphically. Because this chapter is a nonmathematical introduction to projections, I will take a more intuitive, if less rigorous, approach.

Scale varies from point to point on any projection, and at any point the scale may vary in different directions. The variations can be measured by a *scale factor* (SF). The SF is equal to the scale on the reference globe at the point divided by the defined scale. If $SF = 1.0$, there is no distortion.

Distortion is not random on projections; it follows a definite, orderly pattern for each projection. On every projection there is a point (or points) or line(s) that is (are) correct, that is, the SF is 1.0. These are called *standard points* and *standard lines*. For a short distance away from the point or line, there is an area of minimum distortion. This is called the *area of least deformation* or the *zone of best representation*. By matching this zone with the area to be represented and considering the desirable properties, the cartographer can choose a suitable projection. In the discussion of projection types that follows, the zone of best representation for the various groups will be designated. Figure 6.15 shows the pattern of these zones for the major categories of projections.

Cylindrical Projections

If a cylinder of the same diameter as the generating globe is wrapped around the equator of the globe, and the graticule is projected onto the cylinder, a simple cylindrical projection results (Figure 6.15). When the cylinder is unrolled, the shape of the paper is a rectangle, the meridians appear as straight, parallel, equally spaced lines all the same length, and the parallels appear as straight, parallel lines all the same length as the equator. Maps that have this basic appearance are called *cylindrical projections* and vary only in the spacing of the parallels. The meridians on a globe or the earth converge at the poles, but on cylindrical projections, since the meridians are parallel to one another, there is east–west stretching that increases toward the poles. They are also called *rectangular projections*.

Parallels on the earth are small circles and are smaller in circumference than the equator (a great circle), but on a cylindrical projection all parallels are the same length. This again shows the east–west stretching of these projections. Since the cylinder is wrapped around the equator in the *normal case*, the circumference of the cylinder is the same as the length of the equator. Therefore, the scale is correct along the equator and increases poleward. It can be seen that the zone of best representation is along the equator.

Since scale is true only along the equator on these projections, it is customary to label the map “equatorial scale 1:xxx,xxx,xxx” or to use a graphic scale devised especially for cylindrical projections. Since each parallel has a specific ratio with

the equator, a graphic scale for each parallel can be constructed. Figure 6.17 illustrates such a scale for a cylindrical (Mercator) projection with an equatorial scale of 1:1,000,000.

There are many cylindrical projections. Although they all have a family resemblance, they may be constructed to preserve different properties. For example, there are cylindrical equal-area, cylindrical conformal (Mercator), and several compromise cylindrical projections. These projections vary only in the spacing of the parallels.

A subgroup of the cylindricals that is sometimes described are the *pseudocylindrical* projections. These projections have straight parallels with the meridians equally spaced, but the meridians are curved.

Probably the best known projection is the Mercator projection (Figure 6.18), which is a cylindrical conformal projection. It is also one of the most misused of the projections. Gerardus Mercator (Gerard Kramer) created the projection in 1569 to solve a particular mapping problem. The 16th century was a time of exploration and yet a period when few navigational aids were available to sailors. The compass existed and the tools to determine latitude, but longitude was difficult to determine at sea, and great circle routes were hard to follow. The navigator needed a chart that would allow him to make a landfall, despite his relatively poor instruments. Although a short route was desirable, finding port was more important. Mercator's projection was designed to show constant compass directions (rhumb lines) as straight lines, which means that a simple protractor could be used to read and plot compass angles (ship's course) correctly (Figure 6.19). Because it was conformal, the shapes of small features, such as bays and harbors, were correctly represented. This was a major breakthrough for navigation at the period.

Unfortunately, the Mercator projection has been much abused. Because of its rectangular shape and the neat appearance of the graticule, because it is easy to draw and fits nicely on a page, it has been widely used for maps of the world, especially for wall maps in schools. Many significant misconceptions were produced in the minds of generations of students because of this projection's severe distortion of area. Commonly, students would wonder why Greenland was an island, but South America was a continent. Because areal distortion is especially great in the high latitudes, Greenland appears to be about the same size as South America, whereas it is actually about the size of Mexico. In addition, since many people assume that a straight line between two points is the shortest distance on any map, erroneous ideas of distance result. Figure 6.20 shows the relationship between a rhumb line and a great circle

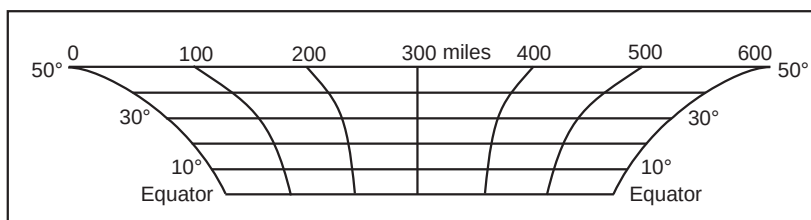


FIGURE 6.17. Scale for a cylindrical projection.

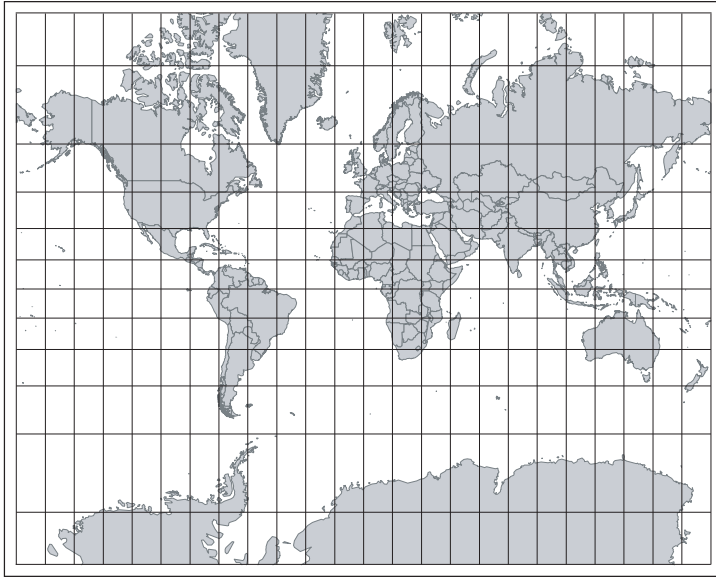


FIGURE 6.18. The Mercator projection was developed by Gerardus Mercator in 1569 for navigation.

route between Los Angeles and London. On this projection, the great circle route appears longer than the rhumb line.

The Mercator–Peters Controversy

Cartographers have objected to the use of the Mercator (or any cylindrical) projection for world maps for many decades, as described earlier. However, in the late

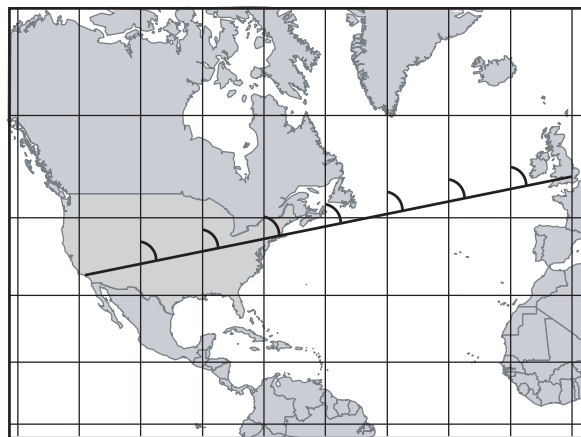


FIGURE 6.19. Rhumb lines or loxodromes are straight lines on the Mercator projection. The cardinal directions, N, S, E, W, are thus shown as straight lines.



FIGURE 6.20. On the Mercator projection a great circle that is the shortest distance between two points on a sphere looks farther than the rhumb line. These distances can be compared on a globe.

1970s, Arno Peters proposed a “new” world map, the so-called Peters projection (Figure 6.21), saying that it was a far superior projection than Mercator, which he believed was used because cartographers were biased toward developed countries. His projection, which is actually the Gall projection developed a century earlier, is an equal-area cylindrical projection, and, according to Peters, shows shapes better than Mercator. In fact, his projection has many deficiencies of its own, some of which are inherent in any cylindrical projection. A number of agencies adopted this projection based on Peters’s persuasive rhetoric and it is now found in atlases and wall maps.

Because of the distortions inherent in rectangular projections, in 1989 the

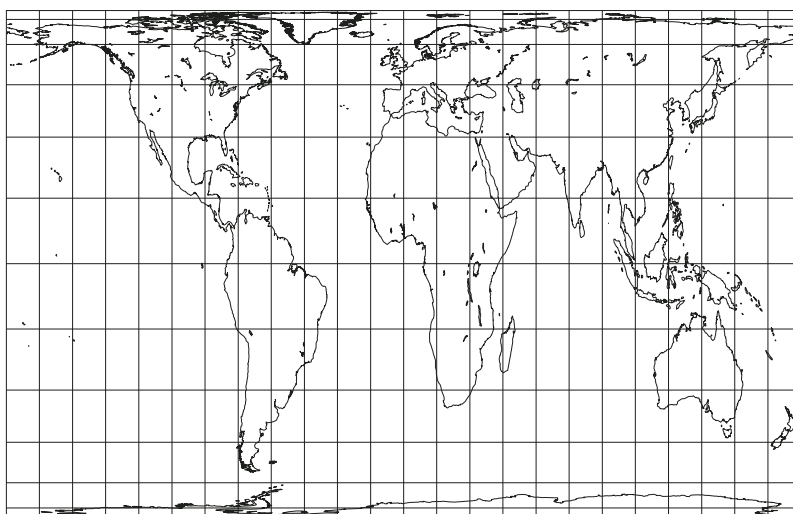


FIGURE 6.21. The Gall–Peters projection was proposed as a replacement for the Mercator, but has the same disadvantages of any cylindrical projection.

American Cartographic Association passed a resolution strongly urging publishers, governmental agencies, and the media to cease using rectangular world maps for general purposes and artistic displays, which was signed by other cartographic and geographic organizations (American Cartographic Committee on Map Projections, 1989, p. 223). Despite this effort, rectangular maps are still found in children's geography workbooks.

Other Aspects of Cylindrical Projections

If it is possible to wrap a cylinder around the equator, it is equally possible to create a cylindrical projection by wrapping the cylinder around some other great circle. If the great circle is formed by a pair of opposing meridians, the resulting projection is a *transverse aspect*. For any other great circle, the projection is an *oblique aspect*. The parallels and meridians look very different in these aspects from the normal or *equatorial aspect*, and some properties are lost. For example, rhumb lines are straight lines only on the equatorial aspect of the Mercator, not on the transverse or oblique aspects. The zone of best representation is along the tangent great circle in any of these cases (Figure 6.22).

It is also possible to create a cylindrical projection that has two zones of good representation, called a *secant case*. This is accomplished with a secant cylinder, that

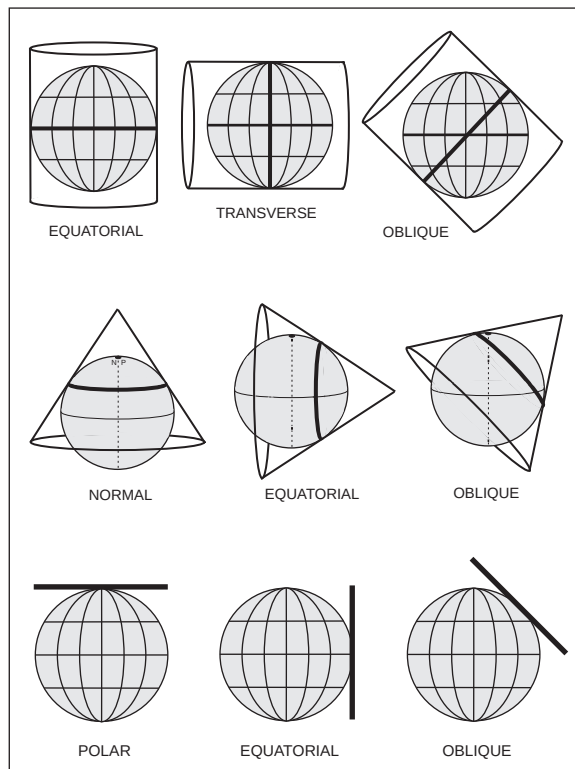


FIGURE 6.22. Projection aspects.

is, a cylinder that cuts the globe instead of encircling it. The small circles where the cylinder enters and exits the generating globe has true representations.

Plane (Azimuthal) Projections

If a plane is placed tangent to the pole of the generating globe and the earth's graticule projected upon it, a *plane projection* is the result (Figure 6.15). Such a projection will be circular in outline and have straight meridians that radiate from the center and parallels that are concentric circles. The spacing of the parallels and the amount of the earth that can be shown will be governed by the position of the imaginary light source. The tangent point or center can be located at the poles, at the equator, or any point between the equator or pole. These create *polar*, *equatorial*, and *oblique* aspects of the projections. Obviously, in the equatorial and oblique aspects, parallels will not look the same as on the polar version, but the various projection properties will be maintained. Some of the plane projections, such as the equidistant, are used more often in oblique aspects than polar.

Since all plane projections have the property of showing azimuths correctly from the center point, these are more commonly called *azimuthal projections*. Any straight line that passes through the center of these projections is a great circle. Another term sometimes encountered for this group is *zenithal projections*. Since the plane touches the globe at the center, the zone of best representation for azimuthals is at the center point. Keep in mind that the zone of best representation is the point where the plane is tangent, and is only at the pole in the polar case.

There are five azimuthal projections in common use (Figure 6.23): the ortho-

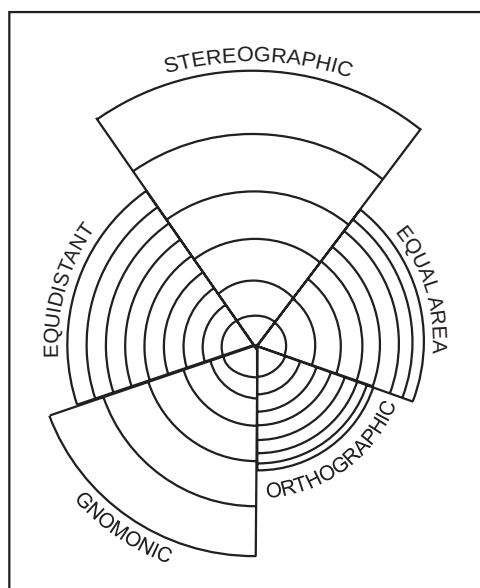


FIGURE 6.23. The five azimuthals in polar case vary only in the spacing of the parallels. Redrawn from Robinson, Arthur H., et al. (1995). *Elements of Cartography* (6th ed.). New York: Wiley. Adapted with permission from John Wiley & Sons, Inc.

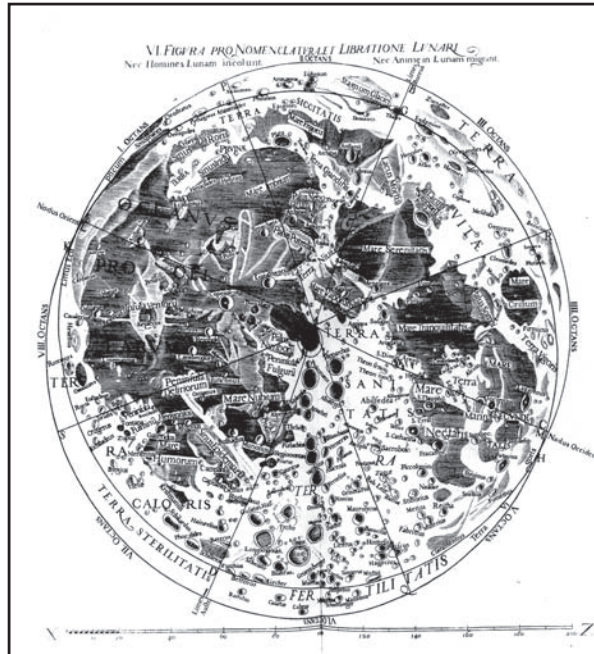


FIGURE 6.24. The moon was often shown in orthographic projection on early lunar maps (Riccioli, 1651).

graphic, the stereographic, the gnomonic, the azimuthal equal-area, and the azimuthal equidistant projections. The appearance of these projections varies only in the spacing of parallels (in the polar case). All can be constructed by geometric projection.

Orthographic Projection

If a light source is assumed to be at infinity, the light rays appear to be parallel. An azimuthal projection produced in this way is called an orthographic projection. We know that Ptolemy used this projection, which he called the “analemma,” for representing the heavens, and may have developed it. The orthographic was also a frequently used projection for early maps of the moon because when the moon is viewed from the earth, it appears to be on the orthographic projection (Figure 6.24).

Figure 6.25 shows that an orthographic projection cannot present more than one hemisphere at a time. When centered on the pole, it has parallels that become closer together as the equator is approached. Other than azimuths being correct from the center and great circles passing through the center being straight lines, both of which are true for all azimuthal projections, the orthographic has no outstanding properties save appearance. The orthographic closely resembles the view we have when looking at a globe, and therefore it is often used when one simply wants to create a good visual appearance.

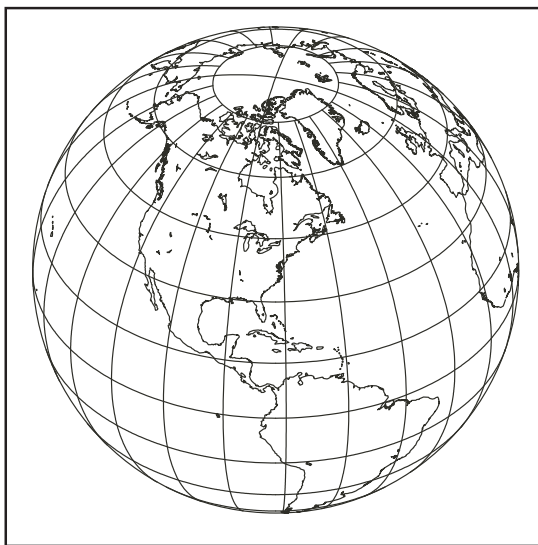


FIGURE 6.25. The orthographic projection in oblique case.

Stereographic Projection

If the light source is assumed to be at the opposite point on the globe from the tangent plane, the stereographic projection is created. Here it is possible to show a little more than one hemisphere, but less than the entire sphere. Normally, however, only a hemisphere is shown; to represent the entire earth a pair of hemispheres is used.

In Figure 6.26, it can be seen that the parallels and meridians cross at right angles and that the spacing of the parallels in pole-centered cases become greater as one approaches the equator. As one goes outward from the center of the projection, east–west stretching is introduced. On the stereographic projection, the spacing of the parallels increases in the same proportion as the spreading of the meridians. Thus, this is a conformal azimuthal projection.

On the stereographic projection, circles on the globe appear as either circles or arcs of circles unless a great circle arc passes through the center of the projection—these appear as straight lines.

Gnomonic Projection

If a light source is imagined to be in the center of the globe, the gnomonic (pronounced *no mon' ic*) projection is created. This appears to be the oldest projection used, since it was known to Thales of Meletus about 600 BCE and he is usually given credit for its development. On this projection, it is impossible to show an entire hemisphere, and the distortion of shapes and areas is extreme (Figure 6.27). Despite these disadvantages, it is a widely used projection because of one important quality: all great circles appear as straight lines, and all straight lines on the map are great circle arcs on the gnomonic projection. It is, therefore, of importance to navigators because great circle routes can be easily plotted.

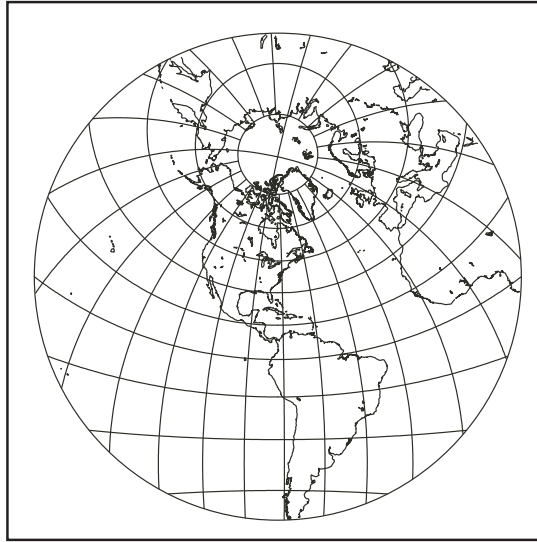


FIGURE 6.26. The stereographic projection in oblique case. The stereographic is a conformal azimuthal projection.

In navigation, the gnomonic projection is used with the Mercator projection to plot courses. Since the compass heading changes constantly along a great circle course, too many corrections are required to fly or sail a true great circle course. On a Mercator the compass heading does not change along a straight line, but this line normally deviates significantly from a great circle route. It is possible, however,

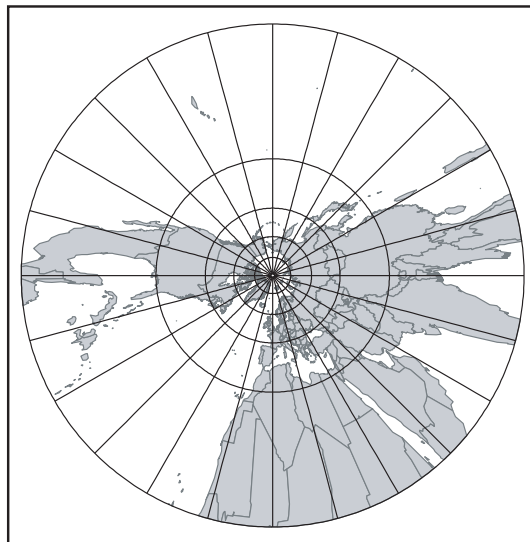


FIGURE 6.27. The gnomonic projection in polar case. The gnomonic has distortion that increases away from the center, but all great circles are represented as straight lines.

to chart a great circle route by plotting it onto a Mercator Projection and following short rhumb-line segments as shown in Figure 6.28. The gnomonic projection is used to find the true great circle and the Mercator to plot the short legs.

Not all azimuthal projections can be visualized as created by projecting a transparent globe by means of a light source. Two important azimuthals are mathematical projections: the azimuthal equal area and the azimuthal equidistant.

Azimuthal Equal-Area Projection

Since east–west stretching is produced by the failure of meridians to converge poleward on the plane projections, compressing must be introduced to get equivalence. On *Lambert’s azimuthal equal-area projection* (Figure 6.29), this is done by placing the parallels closer together the farther away they are from the center. Almost the entire earth can be shown on this projection. Although the azimuthal equal-area projection cannot be projected with a light source and transparent globe, it is possible to construct it graphically.

On this projection, azimuths are shown correctly in common with others of the azimuthal family, but areas can also be compared.

Azimuthal Equidistant Projection

Another commonly used projection is the azimuthal equidistant, which has parallels truly spaced along the meridians (Figure 6.30). This projection is most commonly centered on a place other than the poles to enable one to determine distances from the center to any other place in the world and to determine the starting azimuths from those places. Distances between any other places will not be correct; distance can only be measured from the center point.

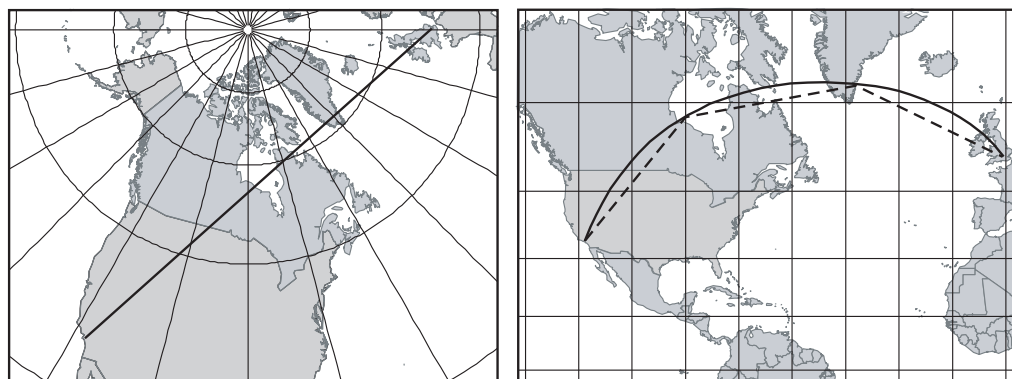


FIGURE 6.28. Great circle routes plotted on the Gnomonic can be approximated with short rhumb lines on the Mercator.



FIGURE 6.29. Lambert's azimuthal equal-area projection in oblique case. The azimuthal equal-area shows sizes of places correctly although shapes are increasingly distorted away from the center.

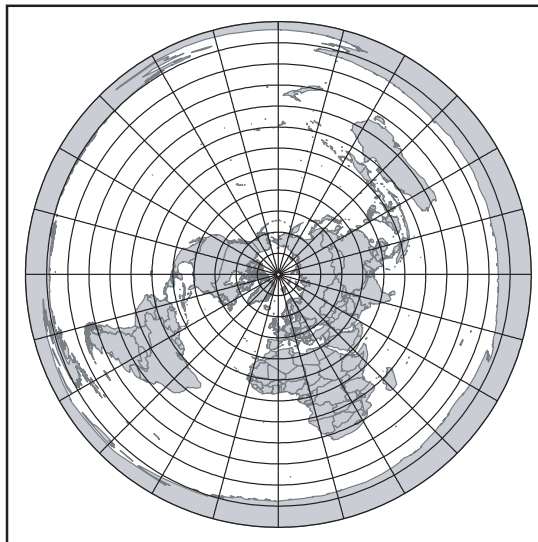


FIGURE 6.30. Azimuthal equidistant projection, polar case. Distances from the center and only the center can be measured accurately. The projection can be centered on any point on the earth. It is frequently used to show airline distances.

Conic Projections

The conic projections, in theory, are created by placing a cone on the generating globe so that it touches a parallel. This parallel is called the *standard parallel of projection* and its length is the same as the parallel on the generating globe. When the cone is flattened, it forms a fan shape, with straight, radiating meridians and curved parallels that are concentric arcs. It is not possible to show the entire earth on such projections (see Figure 6.15).

As with other projections, the zone of best representation is in the area where globe and surface touch, in this case, along the standard parallel, which is thus analogous to the tangent point on azimuthal projections, or to the tangent great circle on cylindrical projections. Distortion increases away from this standard parallel, making conic projections most suitable for midlatitude areas of greater east–west than north–south extent.

It is possible to create conic projections that have two standard parallels by making a cone that cuts the globe. In such secant cases, the projection has two zones of best representation, which are along the lines where the cone intersects the globe. By proper selection of these parallels, the two zones may be brought close enough together to form a single wide zone of little deformation. Two of the most commonly used projections are secant case conics: Lambert’s conic conformal and Albers’s conic equal area.

Lambert’s Conic Conformal

For Lambert’s conic conformal (Figure 6.31), the parallels frequently chosen are 33° and 45° . This makes the projection especially suitable for representing the United States. Although this is a conformal projection and, by definition, not equivalent, areal distortion over the United States is small (5% maximum), and the linear scale error is only 2.5% at a maximum. This projection is also commonly used for aeronautical charts.



FIGURE 6.31. Lambert’s conic conformal. The entire earth cannot be shown on conics and distortion increases away from the standard parallels.

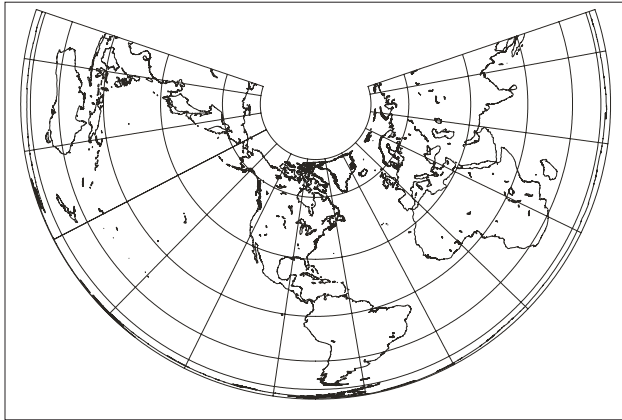


FIGURE 6.32. Albers's conic equal-area projection.

Albers's Conic Equal Area

The conic equal-area projection (Figure 6.32) is also much used for the United States, having standard parallels at $29^{\circ} 30'$ and $45^{\circ} 30'$. Despite being an equivalent projection, shapes are represented well, and for the United States the maximum linear error is only 1.25%.

Other Forms of the Conic

It is possible to place the cone on a small circle that is not a parallel. If a cone is placed so that its axis does not coincide with that of the globe, oblique and transverse aspect conic projections are formed.

An interesting variation of conic projections is the *polyconic*. It might be reasoned that, if a single cone produces one zone of best representation, and a secant cone two zones, it might be possible to create more zones by a series of standard parallels. If one visualizes a series of cones of differing sizes, each touching a different parallel, then one could “peel off” these different standard parallels and place them together along a central meridian (Figure 6.33). To eliminate the gaps between the different parallels, it is necessary to introduce some stretching, but along the central meridian where the strips touch there is a north–south zone of good representation. When extended over the entire earth, this projection is very distorted, as can be seen in Figure 6.32, but for narrow areas of great north–south extent it is very accurate. The polyconic was the projection used for USGS topographic maps until recently.

Mathematical Projections

Mathematical projections include the many that cannot even be imagined as produced by a transparent wire globe and a light source. The shapes of these projections vary widely: oval, circular, heart-shaped, star-shaped, and even armadillo-shaped. Some appear to have been “peeled” from the surface of the globe, although exami-

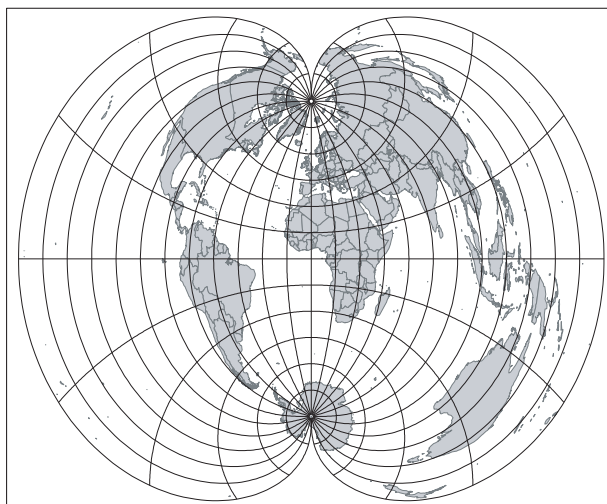


FIGURE 6.33. The polyconic is formed of a series of standard parallels. It doesn't show the entire earth well and is usually used only for small areas, such as topographic maps.

nation reveals that this is not possible. Large numbers of mathematical projections have been developed, especially in recent years, and many are designed for a specific purpose. Many, although by no means all, are equal area. Only four of these will be discussed here for purposes of illustration.

Sinusoidal Projection

The sinusoidal projection, which is also called the Sanson–Flamsteed projection, appears to have been first used by Nicholas Sanson about 1650. This is an equal-area projection that has a straight central meridian and straight, equally spaced, true-to-scale parallels. The central meridian is also true to scale. This makes it possible to measure distance along any parallel (not great circle distances) and along the central meridian. A zone of least distortion is produced along the equator and central meridian (Figure 6.34). Any meridian may be chosen as the central meridian. The projection gets its name from the meridians being trigonometric sine curves. Shapes toward the outer margins of the projection in the high latitudes are badly distorted, but for areas in the center of the projection, such as Africa or South America, the sinusoidal projection would be a good choice.

Mollweide Projection

In some ways, the Mollweide or homolographic projection (Figure 6.35) resembles the sinusoidal. Both are equal area and show the entire earth, and both have a straight central meridian and straight parallels. The Mollweide, however, is an ellipse lacking the pointed poles of the sinusoidal. Only the 40th parallels north and south are correct in length, and the parallels are not spaced truly on the central meridian. Shapes are not as badly distorted in the polar areas as they are on the sinusoidal. On this

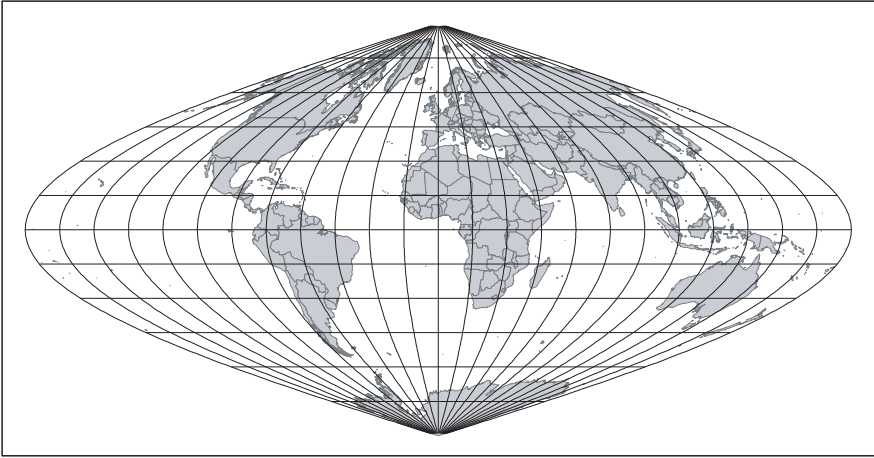


FIGURE 6.34. The sinusoidal projection. This is an equal-area, pseudocylindrical projection.

projection, the zones of best representation are around the central meridian and the 40th parallels.

Goode's Homolosine Projection

In 1923, J. Paul Goode devised the homolosine projection by combining the sinusoidal and homolographic projections. The homolosine is made up of the sinusoidal from 40°N to 40°S and the homolographic from the 40th parallels to the poles, thus combining the “best” parts of the two projections and extending the zone of

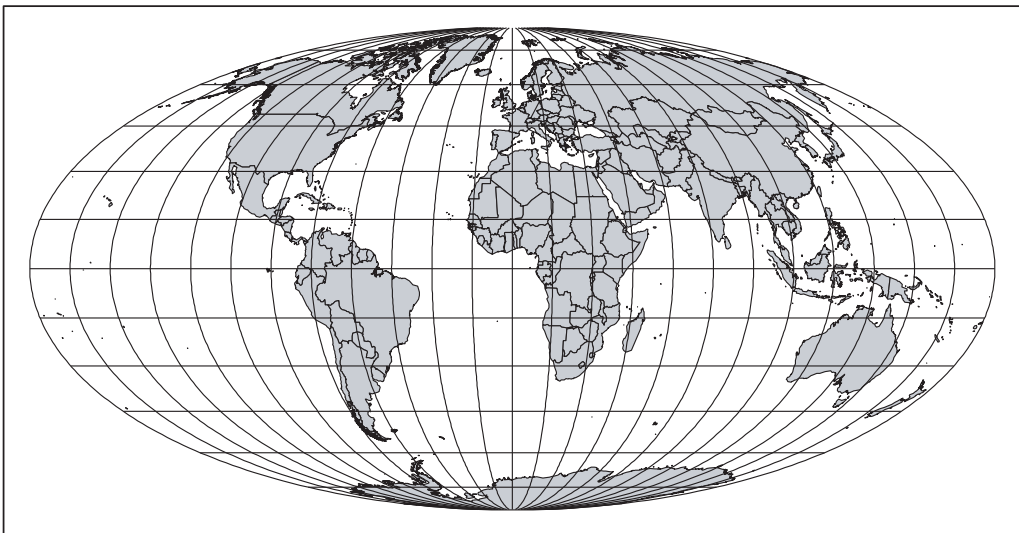


FIGURE 6.35. The Mollweide projection (homolographic).

good representation (Figure 6.36). The projection remains equal area. It is rarely seen except in the interrupted form (see below).

Robinson Projection

Arthur H. Robinson in 1963 devised his projection in an effort to create a world projection that had a pleasing appearance with few obvious distortions (see Figure 6.14). This projection is a *pseudocylindrical* and a compromise in that it is neither equal area nor conformal. It has become quite popular.

Interrupted Projections

With projections of the type of the Mollweide and the sinusoidal, it is possible to interrupt the graticule and thereby create a series of zones of best representation. To illustrate this idea, the Goode's homolosine is used as an example (Figure 6.36). Although this example uses manual construction for explanatory purposes, in practice the projection would be created on a computer.

A line is constructed to represent the equator and marked in the desired number of degrees for the meridians. A central meridian is chosen for each continent and drawn to its proper length. Points are chosen for each interruption. Now the sinusoidal graticule is constructed around each central meridian to the marked interruptions. Each continent has been placed within the zone of best representation for the projection. Note that nothing has been removed at the points of interruption, that certain meridians have been repeated, and that the entire projection is made up of a series of portions of the sinusoidal. This process can be carried out with any projection that has this essentially oval outline. Interruptions may be placed on either land or ocean depending on the area of interest, and any meridian may be chosen as the central meridian.¹

Interrupted projections can also be *condensed*. Condensed projections are interrupted projections that have had an area of little interest removed to allow a larger scale map to be placed on a page (Figure 6.37). When the focus is on land areas, a portion of the Atlantic Ocean is frequently removed. When projections are condensed, there should be some indication on the map that this has been done; otherwise a misleading map is created.

CHOOSING AN APPROPRIATE PROJECTION

Although an unlimited number of arrangements of the earth's graticule is possible, only comparatively few are in common use. The cartographer should be aware of the advantages and limits of at least the most widely used of these.

Although map projections are now created by computer rather than by manual means, this does not relieve the mapmaker of the task of choosing an appropriate

¹Another way of creating an interrupted projection is by joining a series of azimuthal projection segments, as in the star-shaped projection.

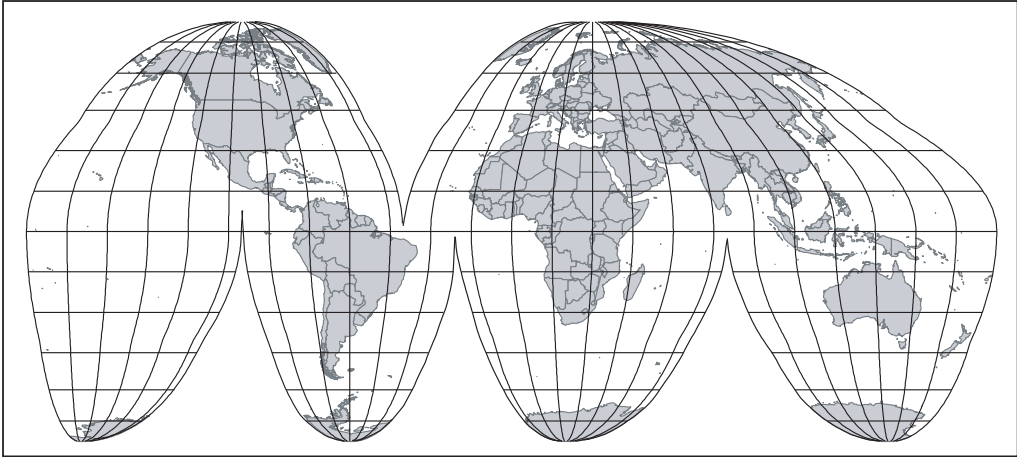


FIGURE 6.36. Goode's homolosine projection is a combination of the sinusoidal and Mollweide (homolographic) projections. It is almost always in interrupted form.

projection from those available. Even if the computer program provides a list of suitable projections for a given task, the cartographer must be able to make an intelligent choice among them. While two or more projections may be suitable, probably not all will illustrate or communicate the given situation equally well. A well-chosen projection can enhance the communicative value of the map; a poorly chosen projection may even mislead the map reader.

To make the best choice, it is necessary to consider the purpose of the map, the subject of the map, the size and shape of the subject area, the location of the subject area, the audience, and the size and shape of the page. Other considerations are the appearance of the graticule, the general attractiveness of the projection, and the availability of the projection within the chosen software program.

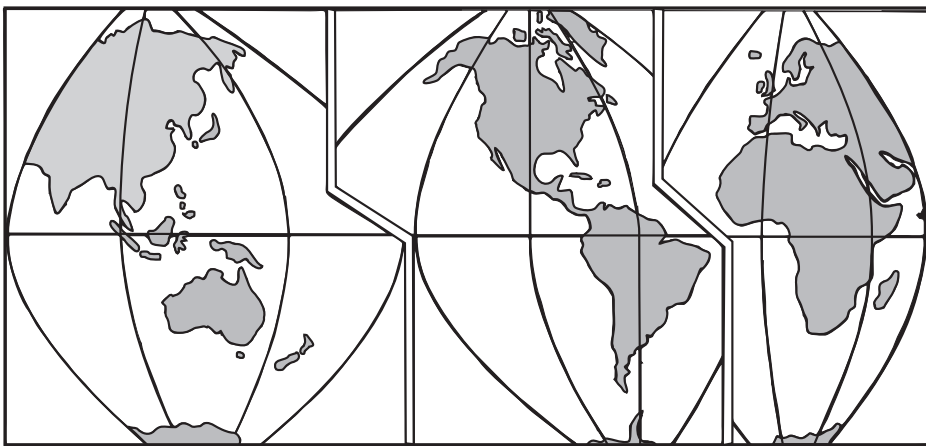


FIGURE 6.37. An interrupted projection can be condensed to gain scale.

Subject and Purpose of the Map

The subject and purpose of the map are the most critical factors for picking a projection. For distribution maps, equal-area projections should be used; for maps showing world distributions, a nonequivalent projection will usually be misleading since quantity and area are related (Figure 6.38). When the distribution is illustrated by dots, the impression of the relative density of the distribution will be distorted if nonequivalent projections are used.

For navigation, maps that show angles or azimuths properly are needed; still other needs might dictate equidistance or conformality. Appendix A will aid in the selection of a suitable projection. The USGS has created a poster of map projections and their properties (see Appendix B).

Size and Shape of the Area

As we have seen in the previous discussion, some projections are best suited for areas of great east–west extent, others for north–south areas. Reversing these would result in serious distortion within the area mapped. The area of interest should always be placed in the zone of least deformation. Therefore the cartographer should be familiar with those zones for the commonly used projection groups.

For small areas (large-scale maps), the choice of projection is seldom of any consequence, since at this scale the differences between projections are negligible. A map of a city or county will look essentially the same on any projection. (There are occasions when projection must be taken into account for small areas, but these are usually of more concern to surveyors than to thematic mapmakers.)

For world projections, the size and shape of the area will determine if an inter-

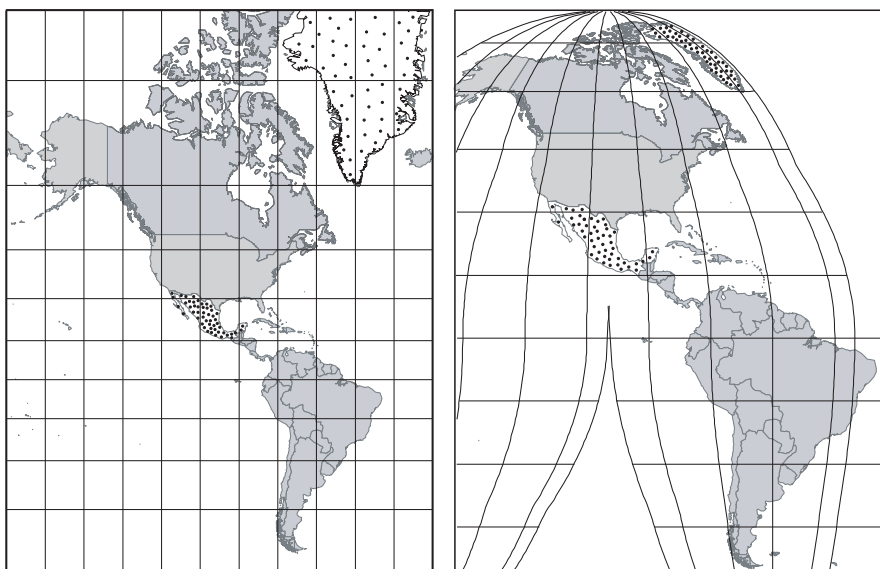


FIGURE 6.38. Greenland and Mexico have the same number of dots, but the conformal projection gives an erroneous impression of density.

rupted projection should be used and where the interruptions should be placed. Obviously, if the distribution being mapped extends over both land and water, an interrupted projection will not be suitable; if the distributions are confined to land, placing interruptions in the ocean areas would be appropriate.

Location of the Subject Area

Just as the zone of best representation of the various projections makes them more suitable for areas of different sizes and shapes, so too are they suited to different latitudinal positions. For example, the conic projections generally show midlatitudes best and especially midlatitude areas that have a greater east–west than north–south extent. An oblique conic or a portion of the polyconic projection could be used for narrow north–south areas.

If one is using a world projection, the issue of centering arises. Normally, one puts the primary area of interest in the center of the map, but for a world distribution map on which no one area is primary, one must decide what to put in the center. Projections in normal or equatorial aspects can be centered on any meridian. Commonly the prime meridian is chosen. However, some have accused cartographers of being deliberately Eurocentric when using the prime meridian because it places Europe in the center of the map. However, studies have found that when students create mental maps of the world, they tend to put their home country or continent in the middle so centering for the audience makes sense. Thus, a reasonable option is to place North America in the center for western hemisphere audiences or Asia for Chinese audiences and so forth. Again, some will criticize the selection, but if the cartographer is aware of potential bias, has considered the audience and purpose of the map, and based the choice on these factors, the choice can be defended.

Audience

Map audiences vary widely, but, as detailed in Chapter 2, maps are generally aimed at a specific audience. When the cartographer chooses a projection, he or she has some knowledge of the degree of sophistication of the map user. Taking this information, the cartographer can decide if the graticule form is distracting or if an interrupted projection might be confusing.

Appearance of the Graticule

The graticule as shown on different projections varies enormously in appearance. In most cases, one does not want a graticule that is so complex and eye-catching that it dominates the page. A very complex graticule might also be confusing for an untrained reader.

Size and Shape of the Page

Since cartographers are often restricted to given page dimensions, this aspect of the format can be a definite factor in choosing a projection. Sometimes a clever choice of projection will allow one to place a map within awkward dimensions. It is also pos-

sible to condense an interrupted projection to gain scale and put a larger scale map on a specific page size.

Orientation Indication

Frequently one sees maps in textbooks, atlases, and other works that do not show the projection name. This is not a problem when the area represented is a small one, such as a city or county, but for larger areas, omitting the projection name does the reader a grave disservice. This is especially so when the graticule has also been omitted, leaving only ticks to show latitude and longitude, or when even the ticks have been left off (a practice that cannot be recommended for world maps). When this is done, the reader has no way of determining where the zone of best representation is found or what the projection properties are.

Except for maps of easily recognizable areas where no reason exists for determining latitude and longitude and where the orientation is obvious, some indication of orientation is needed. The graticule will serve this purpose, as will grid ticks.

North arrows are the most frequently misused indicators of direction, as noted in Chapter 2. A north arrow does not show the general direction of north on maps; it is specific. The north arrow must be true for the entire map, not just one small spot; therefore, unless the meridians are all straight and parallel, a north arrow cannot be used. This means that, except for maps of small areas, the use of such an arrow is limited to cylindrical projections in the equatorial case. It is not suited to conics, azimuthals, or any projection with curved meridians.

Misuse of Projections

As we saw for the Mercator projection, map projections are often misused. The Mercator projection is an elegant and valuable projection, perfectly suited to its purpose when used for navigation; it has been given a bad name because it was used inappropriately. On maps designed for propaganda purposes, the misuse is deliberate and intended to mislead the reader. In other cases, projections are misused through ignorance, inexperience, or negligence.

Projections can be misused or abused in several ways. Incorrect choice of projection is a common error—for example, choosing a non-equal-area projection to illustrate a distribution or other area-dependent topic, such as size comparisons or countries. Using a projection that shows true distance only along the equator is a poor choice for a world geography textbook that includes map questions asking students to determine distances between midlatitude cities.

Another practice that creates misleading maps is the omission of any indication of graticule. Without a graticule (or tick marks) for reference, the reader cannot judge the properties of the projection. Since graticule omission is frequently combined with omission of the projection name, the reader has no way of knowing what can and cannot be shown correctly on the map. In some especially disturbing instances, a completely different frame has been placed around the projection. Richard Dahlberg illustrated an interrupted projection that had the lobes “filled in” by extending Antarctica across the gaps in the projection (Figure 6.39).

A commonly found abuse is the use of the so-called geographical projection (Fig-



FIGURE 6.39. Map projections are often abused. In this case an interrupted projection has had the grid removed and Antarctica spread across the gaps between the lobes. From Dahlberg, Richard E. (1961). *Maps without Projections*. *Journal of Geography*, 60, 213–218. Reprinted with permission from Taylor & Francis.

ure 6.40). It is created by using longitude and latitude as rectangular or x, y coordinates and is similar to plane charts of the 16th century. Mark Monmonier flatly states, “If any projection is worth denouncing, it’s the vaguely named ‘geographical projection’ popular among users of geographic information system (GIS) software” (Monmonier, 2004, p. 176). On the map shown, one can see that the map enlarges the northern states of the United States; this is because, like other rectangular projections, the meridians do not converge at the poles.

Other examples of the misuse of projections abound and yet should not happen. There is little excuse for ignorance given the number of readily available tables of projection use, and no excuse for negligence or laziness. Using an unsuitable projection because it was the most readily available base map is not acceptable.

SUGGESTIONS FOR FURTHER READING

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FIGURE 6.40. The so-called geographical projection is plotted on a rectangular latitude–longitude grid. It has no particular properties and is highly distorted.

- Monmonier, Mark. (1995). *Drawing the Line: Tales of Maps and Cartocontroversy*. New York: Holt.
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