Chapter 2
Choosing a World Map

Attributes, Distortions, Classes, Aspects

Arthur H. Robinson and The Committee on Map Projections

2.1 Foreword

For more than 2000 years mapmakers have been inventing ways to display the entire Earth on a flat surface—papyrus, vellum, metal, paper, or whatever—and now on a TV or computer monitor. The process requires a systematic conversion called a map projection. There is no single solution, and hundreds have been devised. The Earth is round like a ball, and no matter how one flattens the rounded surface the reality of the spherical surface will be variously deformed to a noticeable degree.

Ordinary vision modifies reality in several ways: diminution with distance, perspective convergence, foreshortening because of visual angle, and so on. Even as children we soon learn that the way things are and the way they look differ. Ideally, everyone would know enough about the Earth and the effects of map projection to see past the inevitable distortions in a world map to the Earth the way it really is.

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The ICA Commission on Map Projections hopes that this nontechnical chapter will make the subject of map projections for world maps more understandable. In it we describe the important geometric characteristics of the Earth that can be retained in a flat map of the whole world, as well as the kinds of distortions that may occur. We also show how various classes of projections affect the appearance and utility of world maps. In addition, we describe the patterns of distortion and how they can be displayed.

2.2   Flat World Maps

The Earth is complicated physically, and human life on it is so varied and intricate that we need a variety of world maps to try to understand it. To maintain reality we can make the map on a reduced model of the Earth, a globe; but only half the surface of a globe is visible at once, and the foreshortening toward the edges of the rounded surface greatly alters the appearance of shapes and sizes, Fig. 2.1.

A flat world map is usually much more useful because we can see it all. In addition, flat maps are convenient while globes are awkward.

To convert the entire rounded globe map to a flat map we must somehow "peel" the map from the continuous globe surface in order to lay it out, as in Fig. 2.2. As a matter of fact, the reverse of that process is how globe maps are made: a set of tapered sections, called "gores," is printed flat, as in Fig. 2.3, and then cut out and glued onto a ball.

In each gore there is not much stretching or shrinking, so the map in Fig. 2.3 is a comparatively true, flat, world map. But it is not useful. The multiple discontinuities ruin overall shapes, while important relationships, such as proximity, distance, and direction are essentially destroyed. Continuity in a map is extremely important, and it is far more useful to decrease the number of interruptions by arranging the map
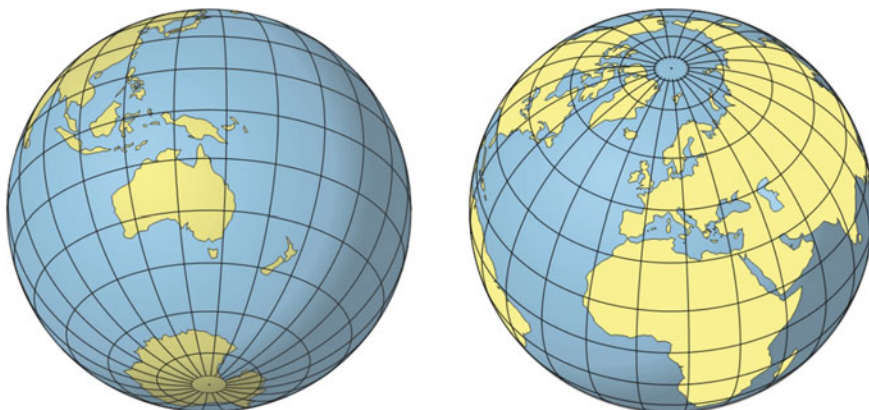
Fig. 2.1 A globe (in perspective projection)
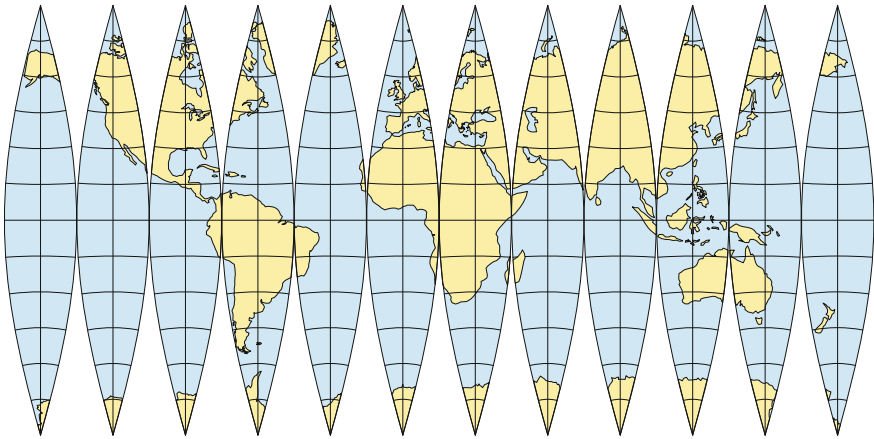
Fig. 2.2 "Peeling" the globe

Fig. 2.3 Globe gores

within a single flat shape, such as an oval, rectangle, or circle. There is then only one interruption, the outside edge. Thus, the maximum continuity possible in a flat map is obtained, but only at the expense of altering shapes, distances, directions, and possibly areas.

Suppose we are looking at a globe straight on; the front is visible, the back is not. If we wish to make an oval world map we must first decide what system to use to flatten the rounded surface and apply that to the front half of the globe. Then, in effect, we cut the globe map down the middle of its back side and pull the two back
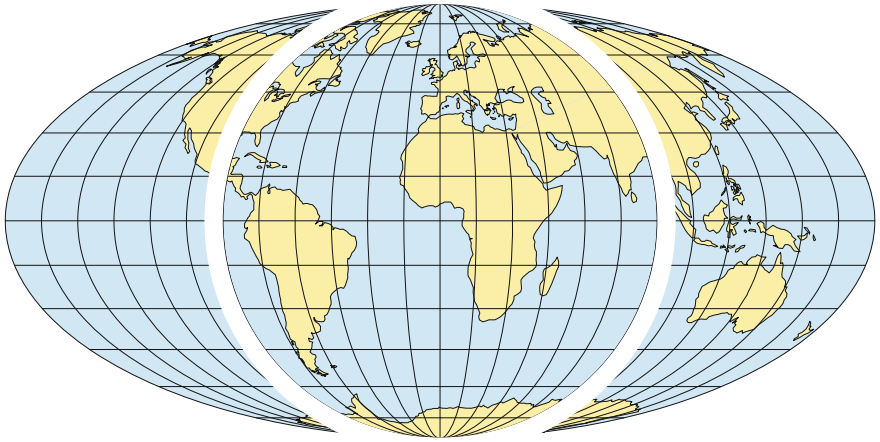
Fig. 2.4 Mollweide projection
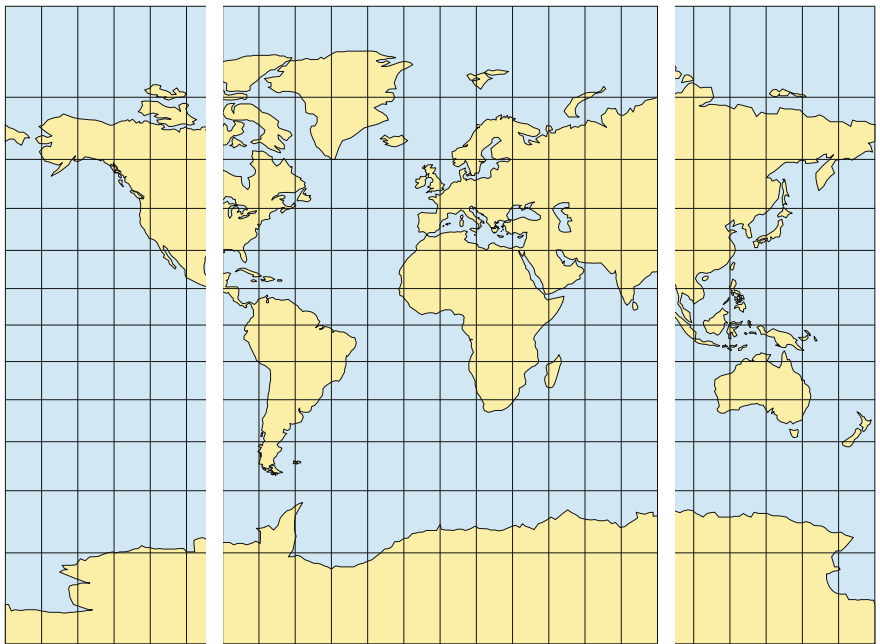
Fig. 2.5 Miller cylindrical projection

quarters around alongside the map of the front half as diagramed in Fig. 2.4. Obviously, the back quarters must be considerably altered in order to make them join the front half.

If we wished to make a rectangular world map we would proceed the same way, that is, by first flattening the front half of the globe map into a rectangular format, and then putting the two back quarters alongside, as illustrated in Fig. 2.5.

They, too, are greatly altered but in a different way as will be explained in a later section.

If we were to follow this same general procedure to make a circular world map we can imagine the back half of the globe being stretched almost beyond recognition and made to surround the map of the front half as in Fig. 2.6. It is important to keep in mind that these separation processes do not lose any part of the globe surface. Thus, the right and left edge of each map in Figs. 2.4 and 2.5 is the *very same* line on the globe, and the outside edge of Fig. 2.6 is the *point* on the globe opposite the center of the map of the front half.

Fig. 2.6 Azimuthal equidistant projection

In the process of making the rounded surface lie flat it is evident that we must stretch or shrink it unevenly. This will alter some of the globe's geometrical qualities, and consequently shapes, sizes, distances, and directions may be changed. Technically, these alterations are called *distortions*. Unfortunately, the word "distortion" suggests something bad; that is an unhappy connotation. The stretching and shrinking can be manipulated so as to produce flat transformations that are more useful than a globe. For example, one can make the direct routes from one place to all others appear simply as straight lines radiating from a central point, as in Fig. 2.6.

There are hundreds of ways to arrange the globe surface within an oval, rectangle, or circle; no one system is best for all maps. Choosing a projection from among the many options requires something like a cost-benefit analysis. For every desirable quality there is often some consequent drawback, and furthermore the distortions associated with any map projection are not uniformly arranged; some parts of a projection are always less distorted than other parts.

Anyone who looks at world maps, on the printed page or on TV, should learn to make allowances for the distortions of shapes, sizes, directions, and distances that are bound to occur. Similarly, a cartographer, designer, editor, or anyone who wants to make a map or have one made for some use should make the selection of a projection an important element in the creative process. Projections should be chosen to best serve the objectives, and just as important, to keep from making a serious error by selecting one that is inappropriate.

2.3   Earth to Globe to Projection

A Ball Is a Ball … Because all world map projections stretch the Earth "out of shape," it is well to reflect on the fact that the object we are mapping is simply a huge ball.

Fig. 2.7 Sphere rotates around an axis
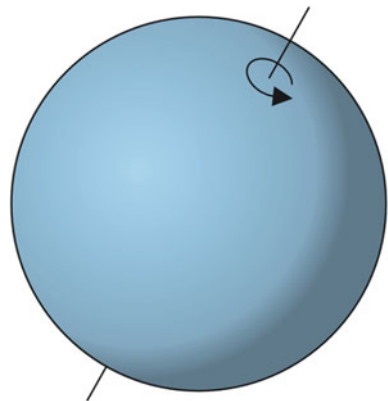
The Earth's surface is almost a perfect sphere that rotates around an axis, Fig. 2.7. Compared to a perfect one of the same size it is only slightly "out of round" due to centrifugal force from rotation. A perfectly proportioned globe 12.0 in. in diameter through the equator would have a polar diameter only 0.04 in. shorter. The highest mountain would be only 0.0083 in. high above sea level (about the thickness of two sheets of this paper). These ratios are important for large-scale navigation and topographic mapping, but not for world maps.

Map Scale. An important key to the distortions in a map projection is an understanding of *map scale*. The scale of a map is not simply the relation between a given distance on the map and the Earth distance it represents. In fact, first of all, all measurements performed on the Earth surface or close to it should be in some way projected onto the Earth's model—a sphere. A map projection is a mapping from the Earth's sphere or a rotational ellipsoid into the plane of projection. It follows that the scale of a map is approximately the ratio between a given distance on the map and the Earth distance it represents. It may be expressed as a relationship, such as 1.0 in. represents 660 mi., or stated as a ratio or fraction with a numerator of one and a denominator designating how many of those same units on the Earth it represents. Suppose, for example, we have a globe with a diameter of 12 in.; its scale will be about 1:42,000,000 because at that size 1.0 in. on the globe represents 42,000,000 in. on the Earth, about 660 mi. In this chapter we will use the sphere as a model of the Earth, because the flattening of the Earth's ellipsoid is so small, that its influence could be neglected for world maps.

Because projection to a flat surface always stretches and shrinks the spherical surface unevenly, there will always be different scales in different parts of a map. That is particularly important on world maps where differences in scale may be extreme. Statements of linear scale for world maps apply only at particular places in given directions.

In describing the relation of the scale at one point on a map to the scale at another point, it is convenient simply to use the terms *larger* and *smaller* (scale) instead of trying to compare the actual numerical values. A "larger scale" means that the scale fraction is larger; for example, 1:30,000,000 is larger than 1:40,000,000, in the same way that 1/3 is larger than 1/4.

Reference Globe. An easy way to visualize the basic transformation procedure is to imagine the Earth first mapped on a sphere or a globe at some desired scale, and then the surface of that globe being laid out flat. The size of the globe that is the model for the flat map is called the *reference* or *generating* globe. The scale of the map will then be the same as that of the reference globe. However, while the scale on the globe is the same everywhere, the flattening process is uneven, and the *actual* scale on the map projection will be different from place to place. We can only say, then, that the scale of a world map is a *nominal* scale, that being the scale of the reference globe. Later in this chapter we will explain how simple inspection of a world map can reveal a great deal about the variations from its nominal scale.

An important note—All the world maps and views of a globe in this chapter on which the continents and seas are shown in colour are based upon a reference globe with a scale of about 1:500,000,000, two views of which *at that siz*e are shown on
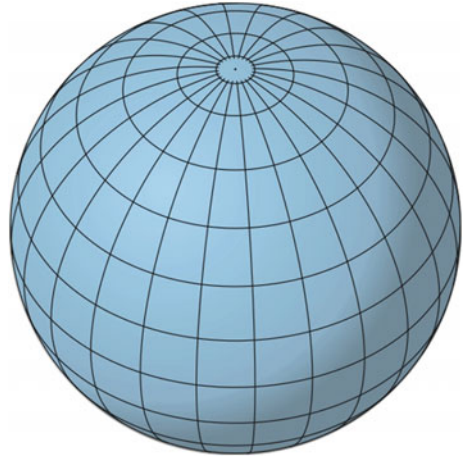
Fig. 2.8 Spherical
coordinate system

Fig. 2.1. All the distortion cartoon maps at the end of the chapter also are that same
nominal scale.

Coordinate Net. To the smooth, rotating ball the ancients fixed a spherical
coordinate system, anchoring it at the two poles, Fig. 2.8. It is made up of
(a) *parallels* of latitude, consisting of a set of *small circles* that denote distance
north and south from the equator (0° Lat.) to the poles (90° north and south Lat.),
and (b) *meridians* of longitude, composed of a set of *great circles* through the poles.
Each meridian from pole to pole is half a great circle, and it designates distance
from the Prime Meridian (0° Long.) east and west to 180° Long. (opposite the
Prime Meridian). Great circles are the largest circles that fit a sphere. Any great
circle divides the Earth in halves, so the equator and all paired meridians are great
circles. The shortest route (the "straight line") between any two places on a sphere
is along the arc of the great circle that joins them.

The parallels and meridians specify the system of geographical directions,
east-west and north-south. It is important to keep in mind that the directions of the
spherical coordinate system has rather different characteristics in comparison with
the directions of the X and Y axes of a rectangular system. For example, except at
the equator north-south directions are not parallel anywhere in a pole-centered
hemisphere. When a selection of parallels and meridians appears on a map it is
called a *graticule*. The arrangement of the graticule lines is important because
directions are defined by them, and it is usually desirable to show directions con-
sistently and as simply as possible throughout a map.

We often think of a particular arrangement of the graticule as the projection.
However, that is not strictly true since it is the *surface* of the sphere that is being
transformed, not the coordinate lines. A projection system can be oriented to the
ball however we want, and it will not affect the resulting geometry of the projection,
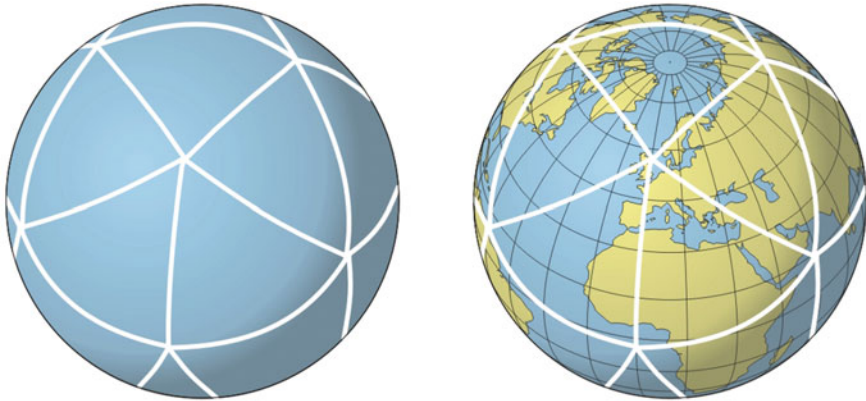
Fig. 2.9   Triangular net on the sphere

but it will greatly affect the appearance of the graticule. This is well illustrated by the series of orientations in Fig. 2.29.

Triangular net. A comparison of the graticule on a flat map with the parallels and meridians on the globe shows how the projection system has stretched, shrunk, and skewed the globe surface. It is, however, often difficult to make comparisons, even when a globe is at hand, due to perspective foreshortening and because the parallels and meridians on the globe are not evenly spaced except in a very restricted way.

More help in displaying comparative distortion is provided by placing a number of geometric figures on the globe and then showing how the projection system has changed them on the flat map. The most successful has been the employment of an icosahedron, a 20-sided geometric solid. When fitted to a sphere it provides a set of 20 exactly alike, equilateral, spherical triangles that cover the globe completely without overlap, and all sides of which are same-length arcs of great circles. The set is arranged on the reference globe for the colored maps in this chapter so that one triangle is centered on the North Pole with one vertex of that triangle located on the Prime Meridian, 0° Long., as illustrated in Fig. 2.9. That set of triangles is shown with white lines on the coloured maps.

*An important note*—Each world map (except Mercator) shows the set of 20 triangles in its entirety.

2.4   Attributes and Distortions

A globe map is "reduced reality" on which sizes and distances are made smaller according to scale, while other important attributes, namely angles, shapes, and direct routes remain the same as on the Earth itself. But when the globe map is transformed to a flat map some combination of these attributes always will be

distorted in various ways. Only sizes and angles at points can be kept throughout a map, but not both on the same map and always with significant other distortions.

Because the several attributes are quite important for many map uses they have led to categories of map projections that have specific names.

Areas. It is desirable to display areas in their correct proportions if sheer territorial extent is important, such as when showing productive cropland or inhospitable climates. Projections that maintain the relative areas of all parts of the globe are called *equal-area* or *equivalent*. Unfortunately, when areas are kept in correct
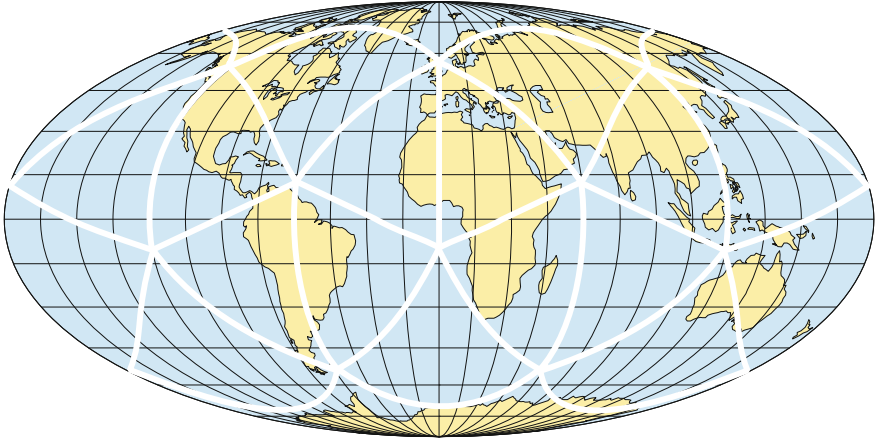
Fig. 2.10 Mollweide projection
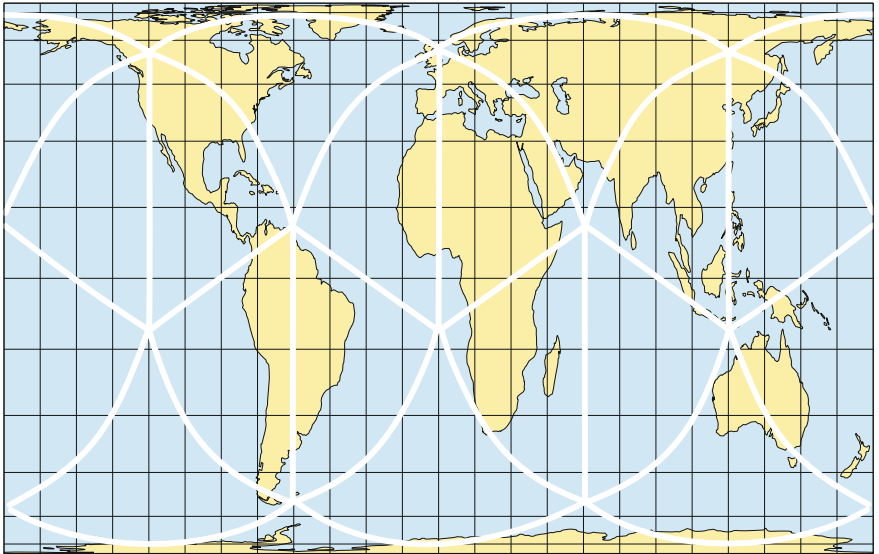
Fig. 2.11 Gall-Peters projection
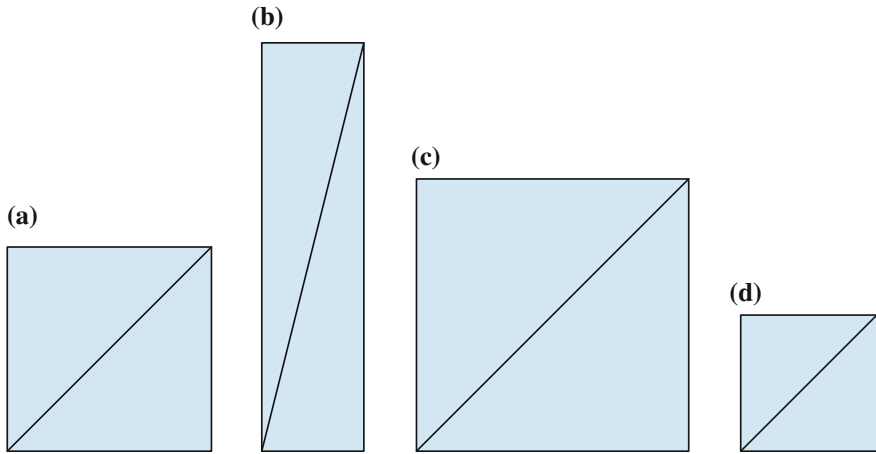
Fig. 2.12 Different transformations of a square

relation then some distances and directions will necessarily be distorted, as in Figs. 2.10 and 2.11.

Angles. On many projections some angles (and directions) at a point may be kept, while others at that same point are changed. For example, if, in Fig. 2.12, square a with the 45° diagonal from one corner is transformed to the rectangle b, the right angles of the sides have not been altered, but the angle of the diagonal has. It is possible to retain correct angles at all *points* only by maintaining the scale the same in all directions at each point, but in so doing the scale will usually differ from point to point. Compare c and d with a in Fig. 2.12.

Projections that maintain correct angles in every direction at each point are called *conformal* or *orthomorphic*. Both terms imply correct shape (and direction), but in practical application those qualities are limited to very small areas. Conformal maps are important tools for navigational, scientific, and technical purposes. Areas and sizes are greatly distorted on conformal projections of the whole world, and maps on those projections are not suitable for general use. Unfortunately, one well-known conformal projection, shown in Fig. 2.13, is too often employed for general world maps. Note the great exaggeration of sizes in the middle and high latitudes of Fig. 2.13. In reality South America is larger than Antarctica! The poles cannot be shown on the Mercator projection because it continues indefinitely to the north and south.

Shapes. The distinctive forms of all parts of the Earth, its continents, countries, seas, and so on, simply cannot be shown on a flat map without deformation due to the inevitable stretching and shrinking. Some representations are much better than others. Compare the nearly true shape of North America on the Orthographic projection (the same as looking directly at it on a globe) with its appearance at the same scale on the Gall-Peters and Mercator projections in Fig. 2.14. The shape is not easy to define. For example, for ordinary people a triangle and a square have completely different shape. In contrast, in the shape theory in mathematics, the two
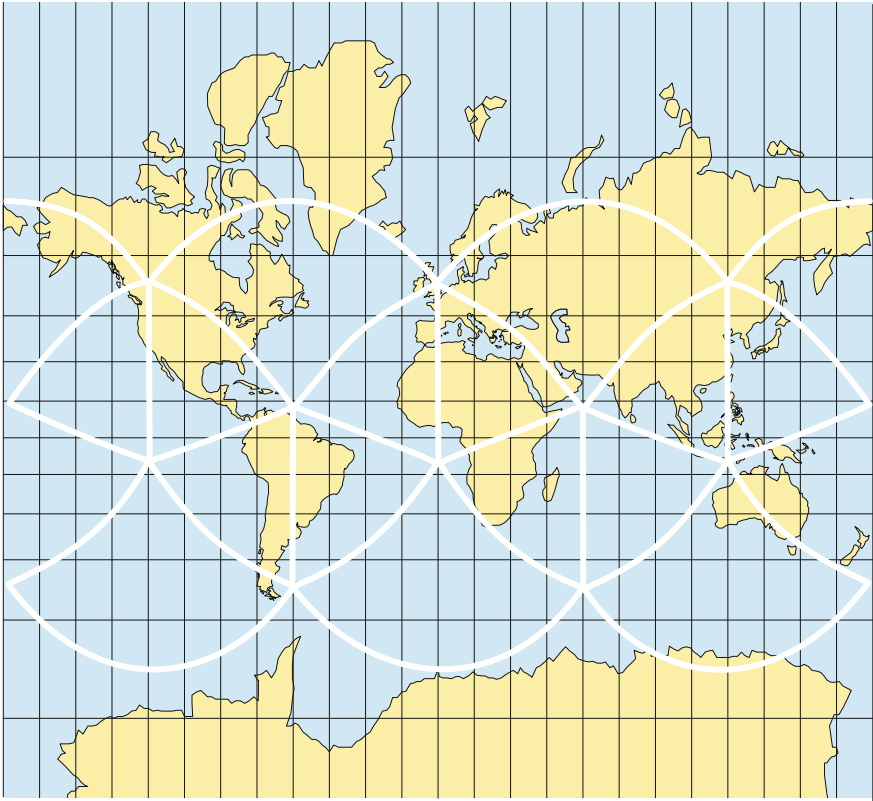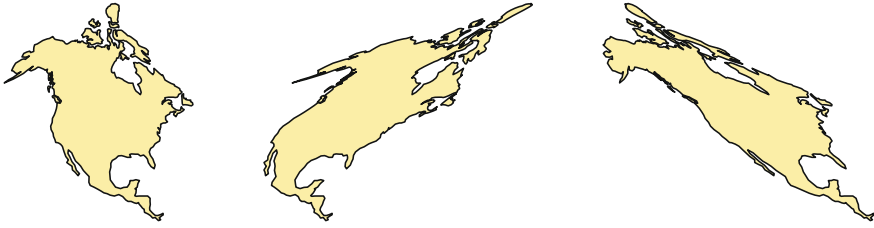
Fig. 2.13 Mercator projection

Fig. 2.14 North America in orthographic, Gall-Peters and Mercator projections

Fig. 2.15 North America in the *center*, on the *left* side, and on the *right* side of a Sinusoidal projection of the world

objects (triangle and square) have the same shape because there is a continuous mapping that transforms the triangle onto the square. On the other hand, if we accept that shape is something that remains unchanged in isometric mapping, then shape is always changed in map projections, because there is no map projection that is an isometry. Due to the fact that shape is not easy to define, this characteristic is generally not in use in the theory of map projections. We prefer areas, distances, and angles or directions as main attributes of any map projection because they are measurable and enable comparison between different mappings.

Unlike sizes or angles, which can be retained everywhere in a projection, shape representation can vary greatly from one part of a projection to another. For example, in Fig. 2.15 North America is shown the way it appears when it is in the center, on the left side, and on the right side of a Sinusoidal projection of the world (Fig. 2.19).

Direct Routes. The direct, or shortest, route from one place to another on the Earth's sphere or on the globe is along the arc of the great circle on which they both lie; that is the spherical equivalent of a straight line on a flat surface. All great circles are smooth curves on a globe, but in most parts of world map projections great-circle arcs become complex curves, except when both places are on the equator or the same meridian. Fortunately, some projection processes make it possible to "rectify" all the arcs from one place to all others so that they appear straight on the map. If the central point is made a pole, as in Fig. 2.16, then, since all meridians are great-circle arcs, all meridians will be shown as straight lines. The direction from one point to another is called an *azimuth* (the angle, in degrees from north, between the great circle arc and the meridian at the starting point). Because all directions from the center on these kinds of projections are correct they are called azimuthal; another term used is *zenithal*.

It is necessary to specify the direction (azimuth) of a great-circle route at the starting point because the coordinate directions in our spherical coordinate system has rather different characteristics in comparison with a rectangular system. Consequently, the relation between Earth's sphere or globe directions and any oblique great-circle arc differs from place to place along it as illustrated in Fig. 2.17 by the great-circle arc between two points on the same parallel.

A projection can be azimuthal and equal-area or azimuthal and conformal, but not both equal-area and conformal since those attributes are mutually exclusive.
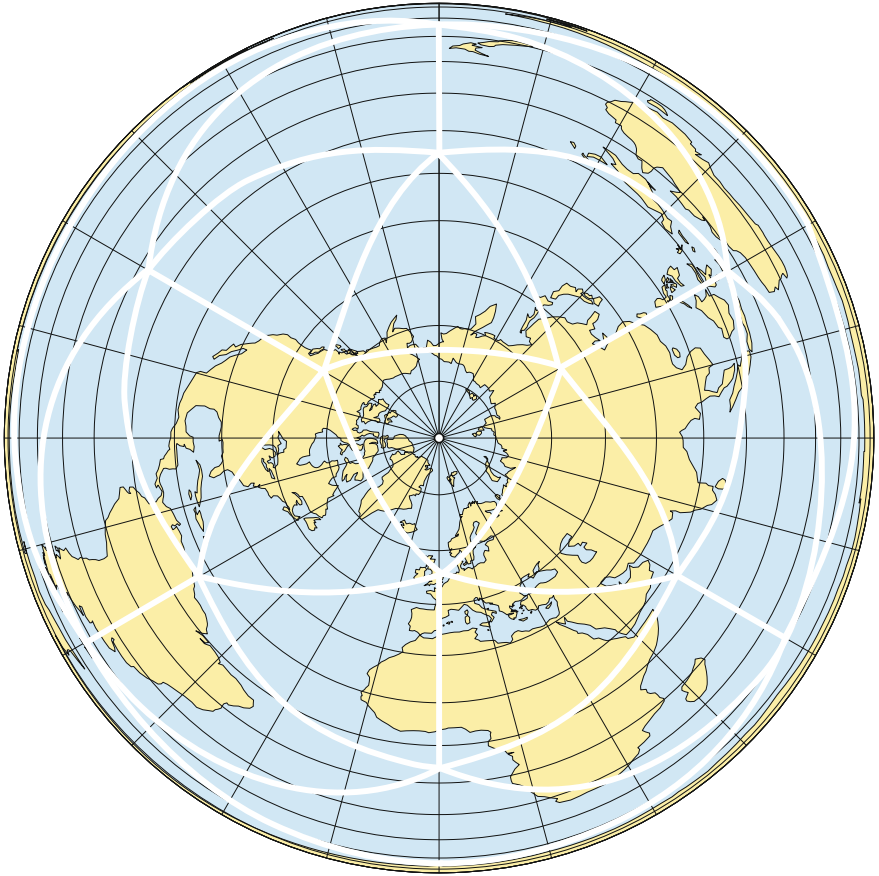
Fig. 2.16 Lambert Azimuthal equal-area projection

The azimuthal conformal projection, the Stereographic, can only show part of the Earth (in fact, theoretically the Stereographic shows the globe without only one point!). Even though the Lambert Azimuthal Equal-Area projection (Fig. 2.16) can portray the whole Earth it is not much used for world maps because shapes are severely distorted in the outer half, as in all azimuthal projections. Note that in Fig. 2.16 the bounding line of the map is the *point* opposite the center point of the map. Since the center is the North Pole, the entire outer edge of the map is the South Pole!

Distances. The topic of distance representation on world map projections is rather involved since the inevitable shrinking and stretching of the globe surface varies from place to place and at most points is even likely to be unequal in different directions. Nevertheless, some of the distance relationships on the globe can be retained in world map projections.

Fig. 2.17 Great-circle
between two points on the
same parallel
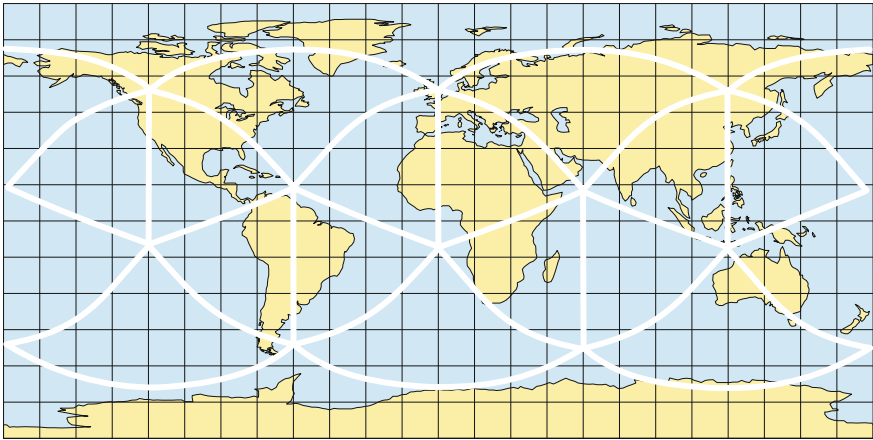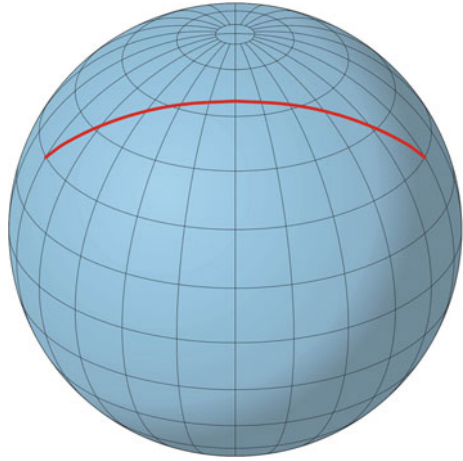
Fig. 2.18 Simple cylindrical projection (the equator and all meridians are length true)

A "true" distance on a map is a line the same length as it is on the reference
globe, regardless of whether it is a great or small circle, straight or curved. In many
world projections one or two lines may be their true lengths. In one projection
(Fig. 2.18) the equator and all meridians are true, but no other line is. In another,
shown in Fig. 2.19, the equator and all parallels are their true lengths. But
remember that the shortest distance between two points on any parallel, except the
equator, is not along the parallel.
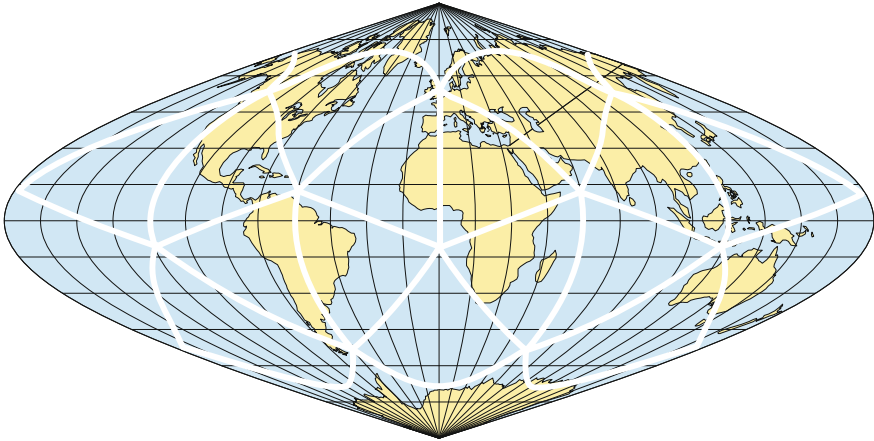
Fig. 2.19 Sinusoidal projection (the equator and all parallels are length true)

To show the direct route and the true relative distance between two places on a map demands that the great-circle arc should be a straight line along which the scale is uniform and the same as the nominal scale of the reference globe. The projection shown in Fig. 2.18 meets this requirement, but only between points that lie on the equator or that are directly north-south of each other. This can be useful for making some latitudinal comparisons, but not for much else.

There is one projection, shown in Fig. 2.20, that displays direct routes and also true distances from *one* point to all others. Because it is shown here with the North Pole at the center all meridians are Fig. 2.21 straight lines, as they are in Fig. 2.16, since meridians are great-circle arcs. In contrast to Fig. 2.16, however, in Fig. 2.20 the parallels are equally spaced showing the true relative distances along the meridians.

2.5   Classes of Projections for World Maps

The term "map projection" suggests the idea of a translucent globe with a light inside shining the map outlines onto a flat surface. As a matter of fact, two well-known and very useful projections for limited areas, the Gnomonic and Stereographic, are derived directly from this perspective model, but most projections are produced mathematically.

The great majority of world map projections may be grouped into classes; each class has a distinctive outline and distortion pattern. Except perspectives, they are all mathematical constructions that have a variety of attributes.

Azimuthal Projections. If we begin with the flat sheet to which the globe map is to be transferred, then one way to proceed is simply to place the translucent globe
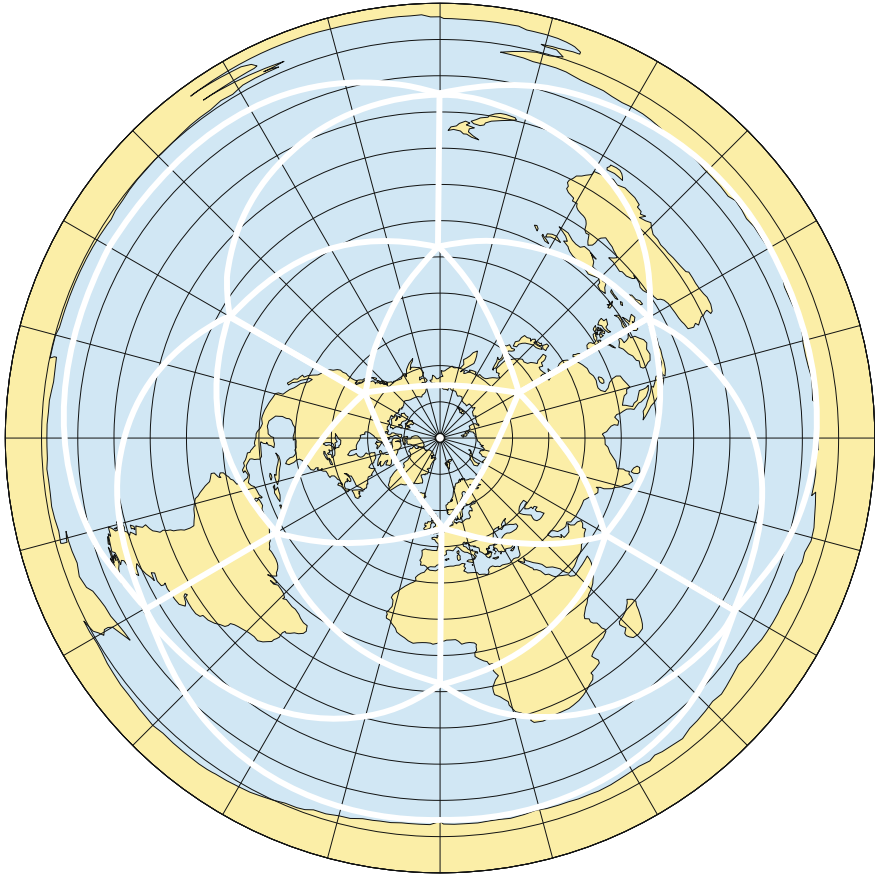
Fig. 2.20 Azimuthal equidistant projection (the true distances along all meridians)

on the sheet and "project" the map to the sheet by some system, such as placing a point of light some distance above the globe and located somewhere on the straight-line going through the center of the globe and that is perpendicular to the plane of projection. Any such perspective or perspective-like transfer will be symmetrical around a center point, resulting in a circular outline on the flat sheet. They are named "azimuthal" rather than "circular" because of their significant attribute that all directions from their centers are correct, which means that all great circles through the centers are straight lines on such maps. An azimuthal projection can be centered anywhere. Any complete azimuthal projection has a circular outline, but the central sections of these projections are often used in rectangular format. One azimuthal projection, the Azimuthal Equidistant (Fig. 2.20), is often used for world maps, but most azimuthal projections cannot be usefully extended to include the whole Earth.
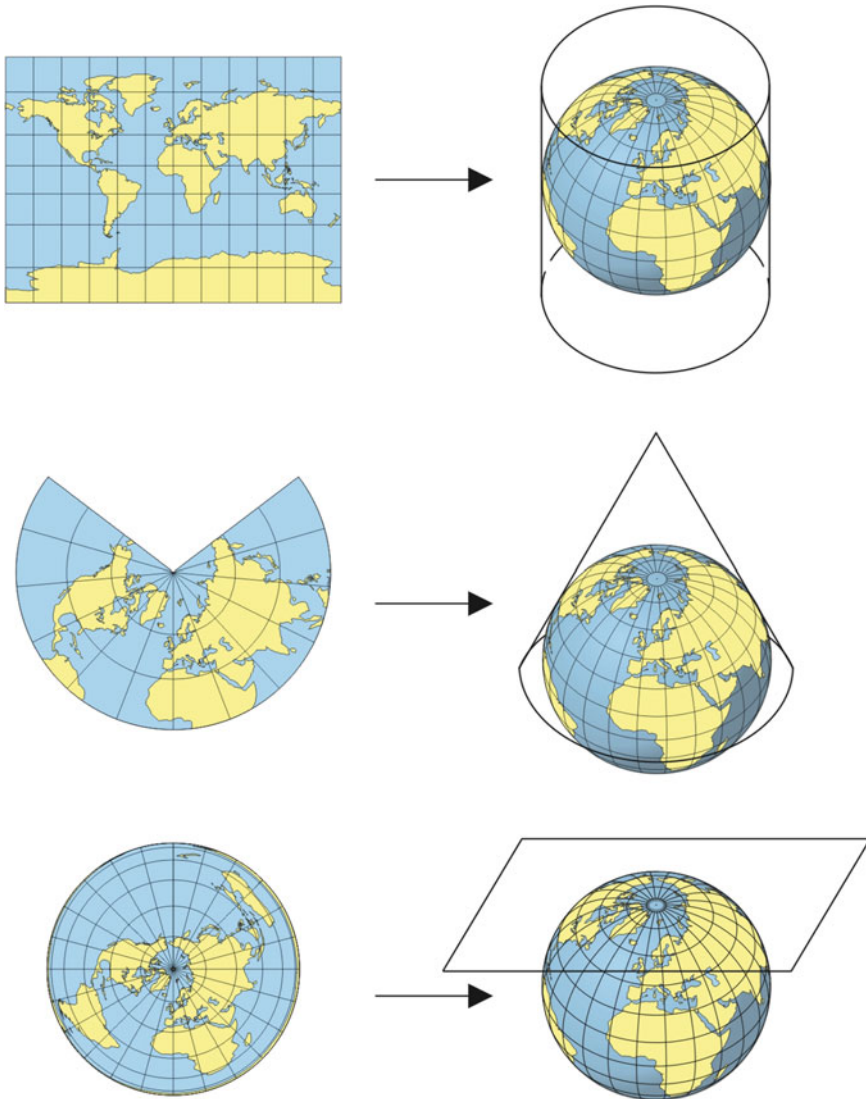
Fig. 2.21 Possible visualisation of map projections

Cylindrical and Conical Projections. Alternatively, the sheet may be formed into a cylinder and wrapped snugly around the globe, or the sheet can be rolled into a cone and perched on the globe. When the globe map has been somehow trans- ferred to the surface of the cylinder or cone the form can be unrolled and laid out flat again. The described approach is rather old-fashioned and true for perspective projections only. The majority of map projections are not perspectives, and they are called cylindrical or conical because they are similar to cylindrical or conical

perspectives by the appearance of graticule. A map designed in a cylindrical projection can be wrapped into cylinder, while one designed in a conical projection can be wrapped into cone.

All cylindrical projections show the Earth within a rectangle. Normally, these projections are arranged so that the parallels of latitude appear as a set of parallel, straight lines crossed at right angles by a set of parallel, straight meridians. Even though the overall shape is always a rectangle, they are called "rectangular" only when the graticule thus appears as a grid of perpendicular lines.

Various cylindrical projections have been devised as "compromise" alternatives to the conformal Mercator projection (Fig. 2.13) and the infinite equal-area series, to which the Gall-Peters projection (Fig. 2.11) belongs, such as the Miller Cylindrical, shown in Fig. 2.22.

Cylindrical projections are often used for world maps simply because a rectangular graticule seems to be psychologically comfortable and the format fits pages and walls. One should have better reasons.

The rectangle, circle, and especially the oval frame or border, include the great majority of projections used for world maps. Conical construction is widely used for maps of lesser scope, but it is rarely used for world maps.
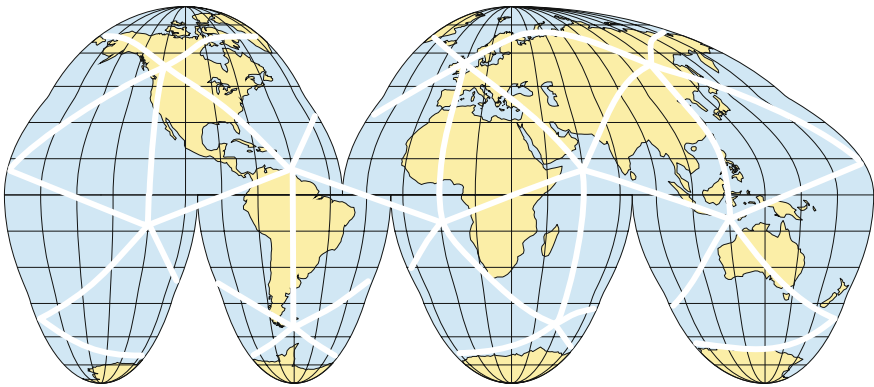
Oval Projections. Although all these projections are basically oval, they can have noticeably different shapes. Compare the Sinusoidal projection (Fig. 2.19) with the Robinson projection shown in Fig. 2.23. Some, like these, are called
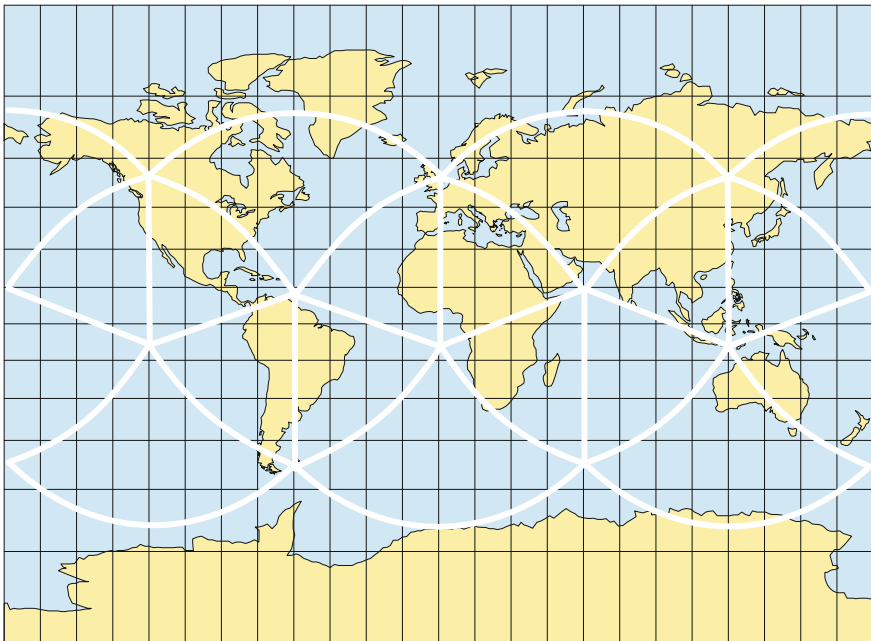
Fig. 2.22 Miller cylindrical projection
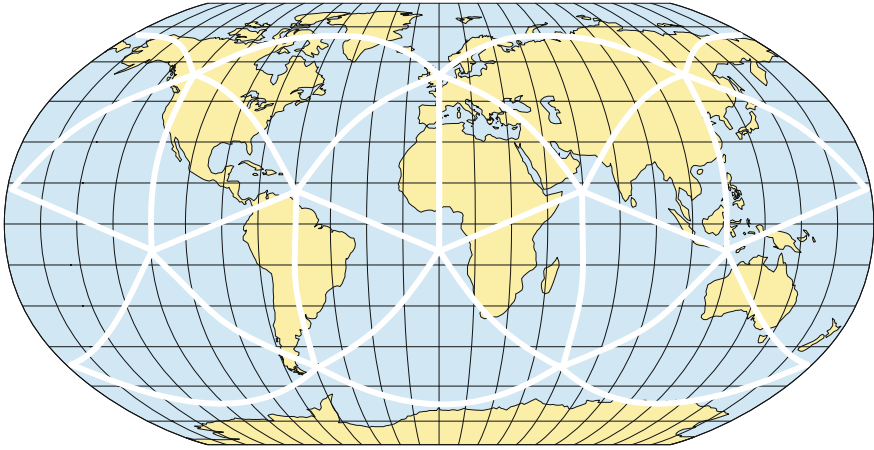
Fig. 2.23 Robinson projection

Fig. 2.24 Goode Homolosine projection

"pseudocylindrical" because they have some of the structural characteristics of cylindrical projections, such as one set of straight, parallel small circles crossed by equally-spaced, but curved, great circles. The primary use of oval projections is for world maps, but their central sections are sometimes used for maps of lesser areas.

   Miscellaneous Projections. This class includes those that do not fit in the other three categories of world map projections. Only a few in this class are often used. One such is an "interrupted" projection (actually more interrupted!) formed by repeating and fitting together the less-distorted sections of one or two projections, usually oval. An example is the equal-area Goode Homolosine projection, shown in Fig. 2.24, that joins the Sinusoidal and Mollweide projections. The lands could just as well be interrupted to show the seas to better advantage.

Fig. 2.25 Van der Grinten projection

Another is the Van der Grinten, a circular but not azimuthal projection, shown in Fig. 2.25. Usually much of the polar sections are cut off because distortion is extreme there, as well as to give the map a rectangular format.

Map projections in the above classes may, of course, have some, none, or a combination of the various useful attributes.

2.5.1 Aspects of Projections

One part of a smooth sphere is curved exactly like any other part even though there are lines on it displaying a graticule and it shows geographical features. No matter how it may be turned with respect to a flat map surface a given projection system

will produce maps that have exactly the same distortion pattern. At the same time, the way the globe is turned will have considerable effect on the looks of the graticule and the geographical features on the map because that shifts them in relation to the distortion pattern.

There are three classes of aspects. The three classes are generally called *direct*, *transverse*, and *oblique*. Sometimes a few other terms are used in place of these in particular cases: "equatorial", "conventional", "normal", and "polar." Their use will be identified below. Remember, no matter what the graticule looks like or how the geographical features are displayed on the map, the fundamental patterns of distortion are not affected. We illustrate the three aspects, with typical appearances of the graticule, by means of representatives of the three major classes of world map projections:
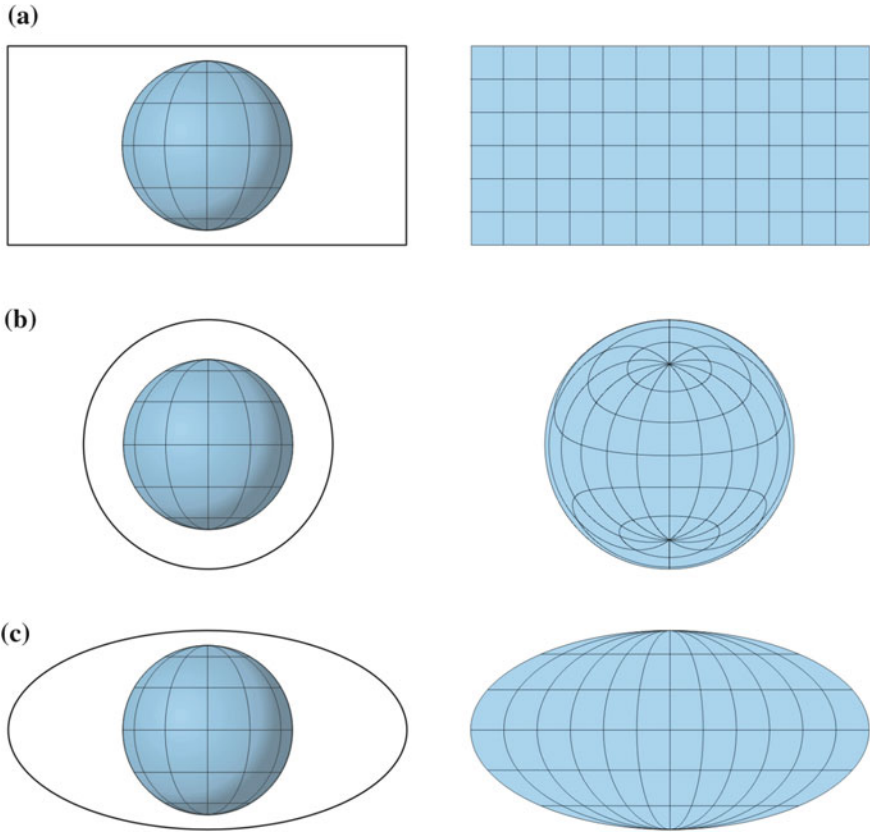
A—Simple *cylindrical* projection
B—Lambert *azimuthal* equal-area projection
C—Mollweide *oval* projection

When one is faced with deciding which world map to use, its aspect is an important consideration. The appearance of the graticule is particularly important. It is clearly an advantage to display the graticule in a way that allows easy recognition of basic directional relationships and so that its appearance does not perplex or perhaps even disconcert the viewer.

Normal Aspect. This is the name for the aspect of cylindrical and pseudo-cylindrical projections of the Earth's sphere when the projection of equator is a straight-line positioned in the middle of the map, while one pole is projected at the top and the other at the bottom of the map. This is also called the "equatorial", "direct" or "conventional" aspect for the cylinder or oval. In every case this results in a straight-line, central equator crossed at a right angle by a straight central meridian, as diagramed in Fig. 2.26.

Transverse Aspect. This is the name for the aspect that results when the projection of poles are points positioned on a meridian that appears horizontally (or vertically) in the middle of the map. In transverse cylindrical and oval projections one great circle (a pair of meridians) will form a central straight line through the long dimension of the projection outline, and a pole will be located somewhere along that line. If the pole is centered on an oval projection or, on a cylindrical projection, anywhere along the paired-meridian straight line, that will be crossed at a right angle by another pair of straight-line meridians. Except for the straight-line great circles and the bounding lines of cylindrical projections, most other elements of the graticules of these cylindrical and oval projections will be complex curves.

In all transverse azimuthal projections the meridians, being arcs of great circles, are straight lines radiating from the central pole at their correct angles. The parallels are circles concentric around the center pole. If the other pole can be shown it is the bounding circle. The only difference among the graticules of the polar aspects of the azimuthal projections is in the spacing of the parallels. The relationships of the transverse or polar aspects are diagramed in Fig. 2.27.

(a)

(b)

(c)

Fig. 2.26 Normal aspects

Oblique Aspect. This name applies to those aspects that are not direct nor transverse. In this aspect the graticules of cylindrical, azimuthal, and oval projections will usually appear as arrangements of complex lines, although the central sections of azimuthal projections may appear nearly "normal." These relationships are diagramed in Fig. 2.28.

Note that since the axis of the globe can make any angle with the plane between 0° and 90°, each world map projection system can have innumerable oblique aspects. For example, Fig. 2.29 shows how the appearance of the graticule changes on a Mollweide projection when the axis of the globe is tilted at progressive 10°-intervals from 0° to 90°. They are all the same projection system with the same pattern of distortion. Nonsymmetrical graticules for projection systems are produced if the axis of the globe is tilted in still other directions.
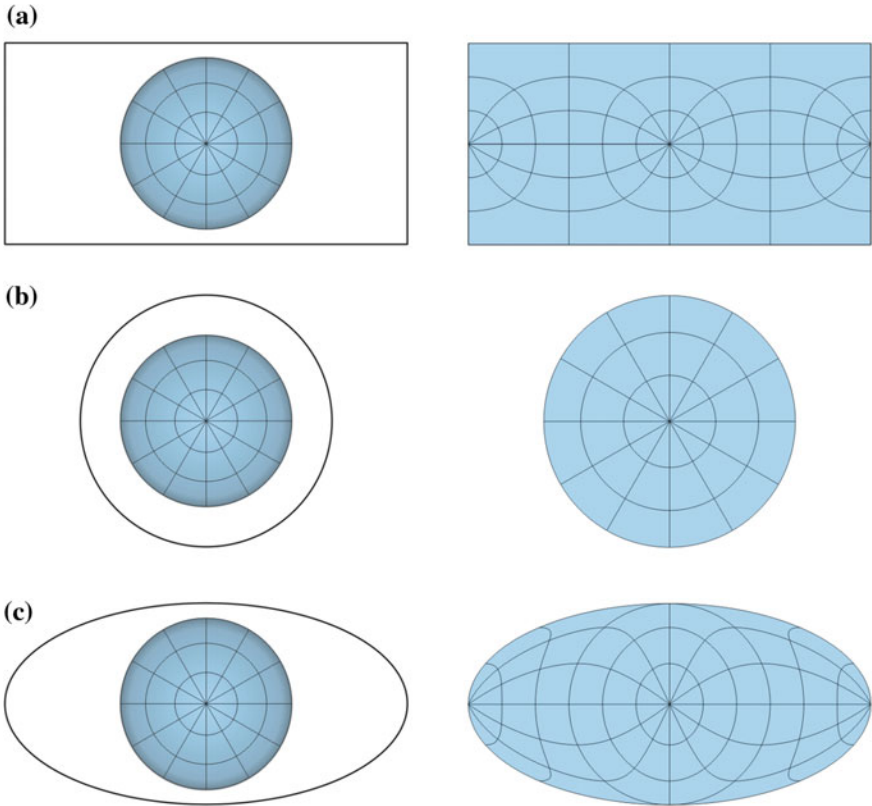
(a)

(b)

(c)

Fig. 2.27 Transverse aspects

2.6   Recognizing Distortion

Most people probably understand, perhaps only vaguely, that flat world maps must somehow distort the globe map. But just knowing that it occurs is not very satis-fying; it would be much better to know how and where. Ideally there would be some kind of summary index, such as a letter grade of a, b, c, or a grade-point average, that could be used to rank world map projections. Unfortunately, that is not possible. As an alternative the average user of maps can easily deduce some aspects of distortion merely by observing the graticule. Another approach is to learn to recognize the general patterns of distortion associated with the overall shapes of world maps.

   Analysis of Distortion. Only informational publications like this ever display, in addition to the graticule, any guide to the distortion, such as the set of equilateral spherical triangles. Unfortunately, the graticule is rather perplexing to many who are not very familiar with the looks of a globe, and this is especially so with regard

(a)

(b)

(c)
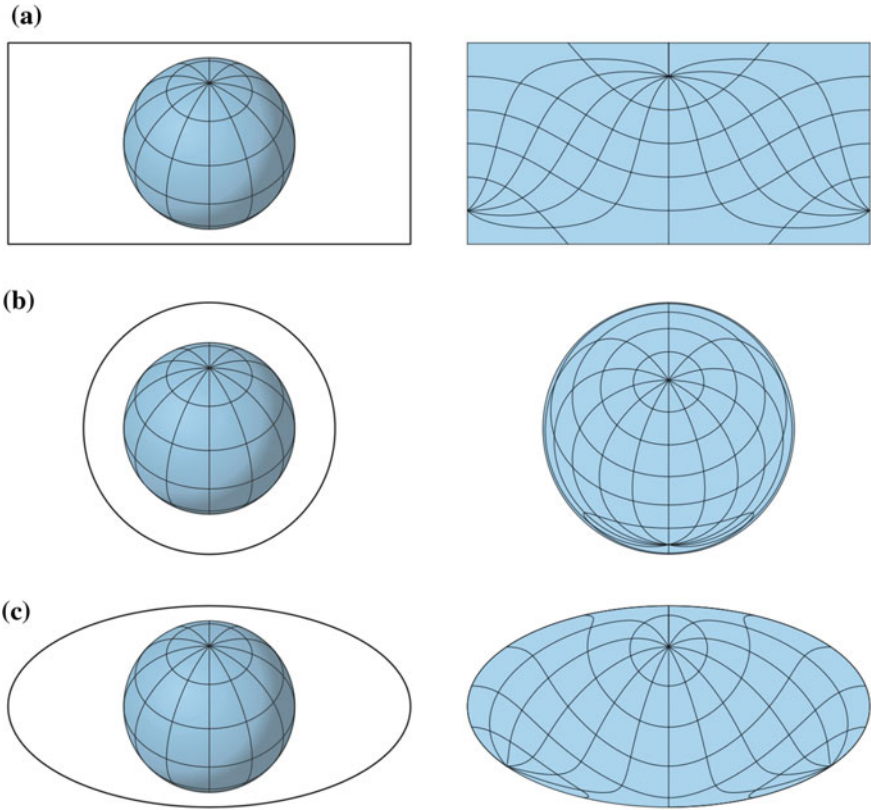
Fig. 2.28 Oblique aspects

to the complex of wavy lines on maps in oblique aspect. On the other hand, the graticule on maps in normal aspect can be a help in recognizing how the projection system has enlarged or diminished sizes, elongated or shortened distances, altered angles, and so on. One need only keep in mind a few basic facts about the spherical coordinate system.

Seven of the characteristics of the graticule on the globe are useful for this kind of reasoning. Assuming a perfect sphere, as we can for world maps, they are:

1. All meridians converge to a point at each pole.
2. All parallels are parallel.
3. All parallels and meridians intersect at right angles.
4. All meridians are spaced equally on each parallel.
5. All parallels are spaced equally on each meridian.
6. Parallels and meridians are spaced equally at the equator.
7. Meridians at 60° Lat. are half as far apart as are the parallels at that latitude.
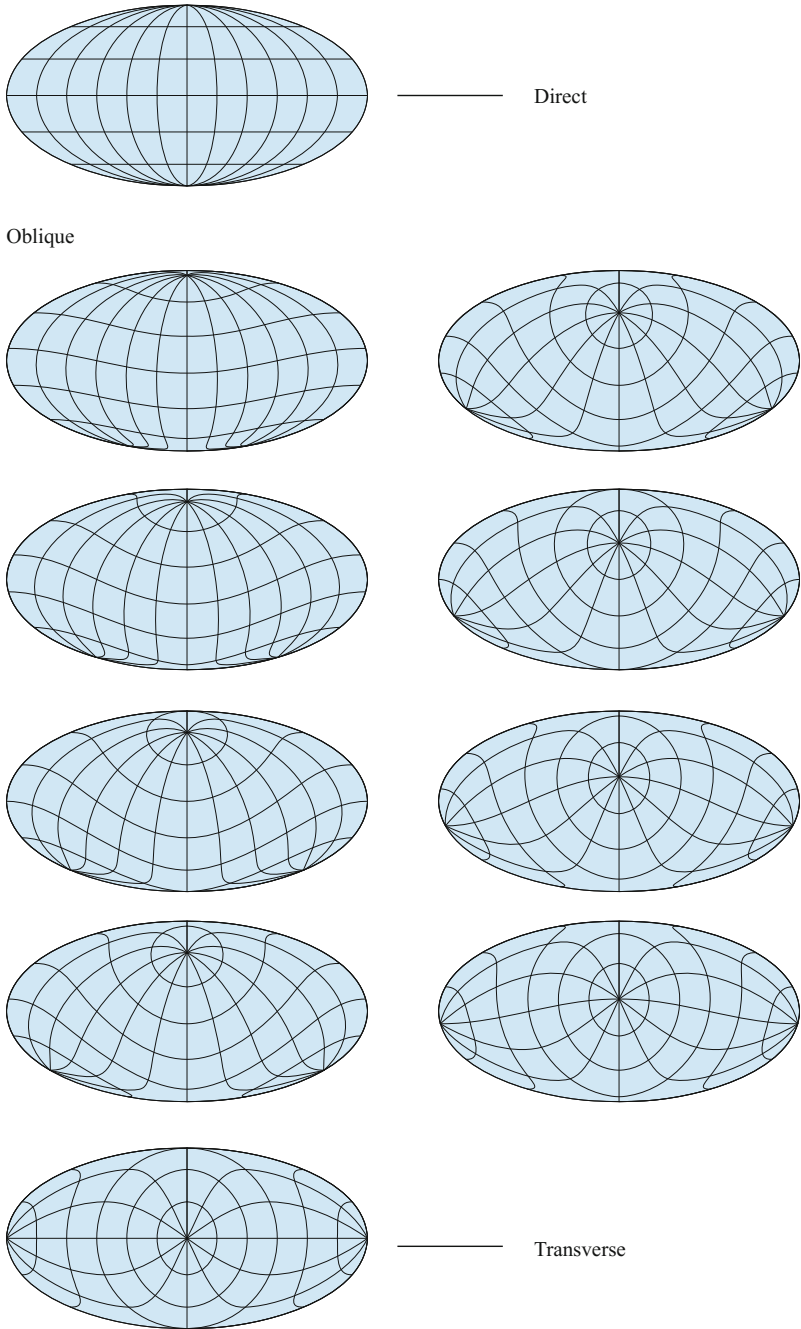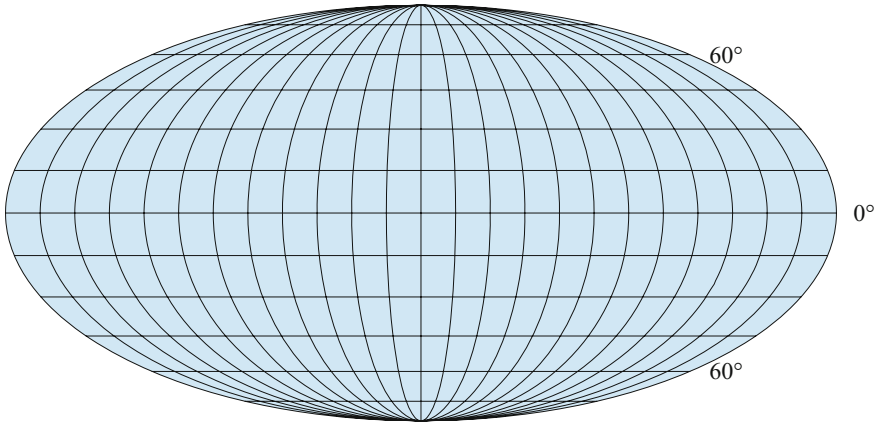
Direct

Oblique

Transverse

**Fig. 2.29** Appearance of the graticule changes on a Mollweide projection

Fig. 2.30   Mollweide projection

When one compares these facts with the appearance of the graticule of a map on which both parallels and meridians are shown at equal-degree intervals, such as 10°, 15°, or 20°, some useful relationships may be inferred. Two projections shown in equatorial aspect, each with a 15°-graticule interval, provide examples.

An analysis of the graticule of the equal-area Mollweide projection, shown in Fig. 2.30, allows the following conclusions. The numbers in parentheses refer to the foregoing list.

Only characteristics (1), (2), and (4) are retained. Meridians and parallels do not intersect at right angles (3) anywhere, except along the equator and the central meridian, so angles elsewhere must be altered. Parallels are closer together toward the poles (5), so distances there must be somewhat shortened north-south. Meridians are nearly, but not quite, half as far apart as parallels at 60° Lat. (7).

Unfortunately, the conformal Mercator projection, shown in Fig. 2.31, is often used for general world maps. An analysis of its graticule provides abundant evidence of why it is an unsuitable choice. Characteristics (2), (3), (4), and (6) are retained, so one can assume that the angles and areas in the equatorial regions are quite well displayed. On the other hand, meridians obviously do not converge (1), so the higher latitudes must be greatly distorted. Parallels are not spaced equally on meridians (5), but become increasingly farther apart toward the higher latitudes. Since the parallel of 60° Lat., is shown the same length as the equator, it must be twice as long as it is on the globe (7), while the distance between parallels right at 60° seems about twice what it is at the equator. Accordingly, areas at 60° Lat. are four times as large as they are on the reference globe. Furthermore, because the expansion increases steadily poleward from the low latitudes, the middle and high latitudes must be much enlarged, and sizable areas in those regions must be greatly distorted.

60°

0°

60°
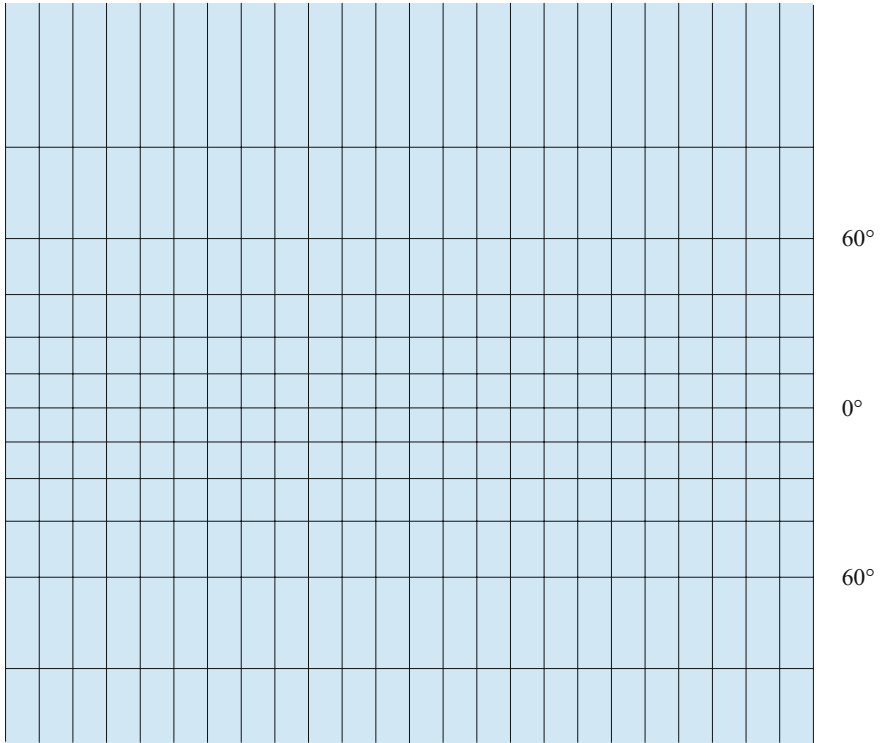
Fig. 2.31 Mercator projection

Patterns of Distortion. The distortions of distances, sizes, and angles generally vary from place to place over a projection, and the overall outline of a projection is an important clue to its pattern of distortion, that is, to the way the distortion is arranged.

The cylindrical, azimuthal, and oval classes have distinctive patterns. In general, whatever the distortion of distances, sizes, and angles may be in a projection it will be a minimum along the true-scale lines or standard lines (the same length as those lines on the reference globe), and often the scales in other directions on those lines will not be greatly different. The distortion will increase perpendicularly away from the standard lines in cylindrical projections and radially from the true-scale point in an azimuthal projection, as diagramed in Fig. 2.32a, b, in which the darker the shading, the greater the distortion.

There could be two standard lines in cylindrical projections and the distortion will increase perpendicularly away from them in both directions as diagramed in Fig. 2.32c.

The oval projections have patterns of distortion quite different from the cylindrical and azimuthal patterns. In general, they have two "areas of strength" aligned with the perpendicular longer and shorter axes of the oval. Normally, these
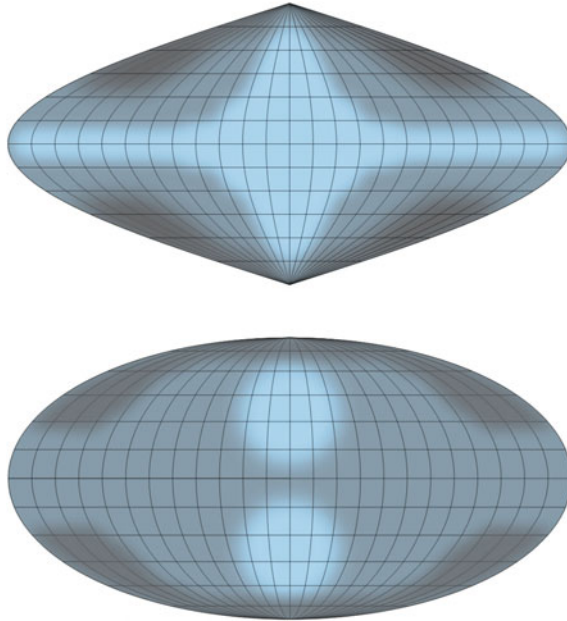
Fig. 2.32 Patterns of
distortion in different map
projections
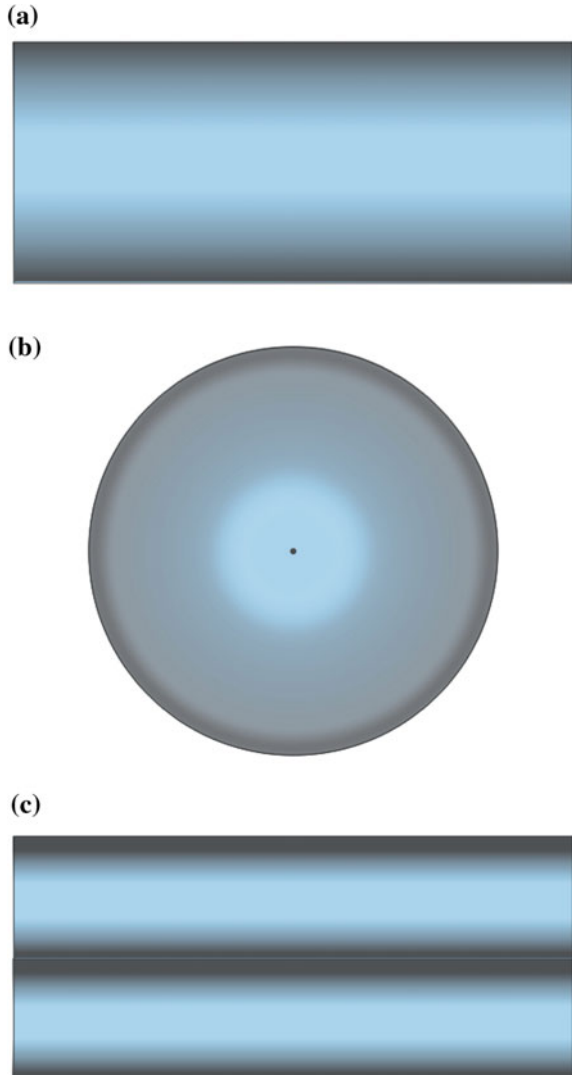
projections are oriented with the long axis horizontal and the major difference
among them is the way the distortion is arranged along the central, vertical axis.
Two examples are shown in Fig. 2.33.

In almost all continuous oval projections there are four areas of maximum
distortion symmetrically positioned in the outer sections of the four quadrants.

The advantage to be obtained by interrupting a projection so as to repeat the less
distorted sections is illustrated in Fig. 2.34. In addition to being interrupted the
projection is a combination of two equal-area projections, the Sinusoidal (better
shapes in the equatorial areas) and the Mollweide (better shapes in the high

Fig. 2.33 Patterns of distortion in sinusoidal and Mollweide projections
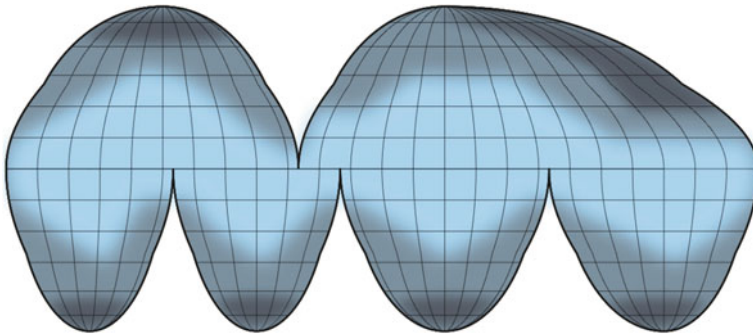
Fig. 2.34 Interrupted Goode Homolosine projection

latitudes), in order to minimize the total amount of inevitable distortion. The additional interruptions violate even further the inherent continuity of the surface of the globe, but as shown earlier, distortions may be considerably reduced by interrupting the surface of the globe map in many places. The question of whether the disadvantage of lack of continuity is worth the advantage of less distortions is one that must be decided in terms of the use to which the map will be put.

2.6.1   Distortion Cartoons

As described earlier, the graticule itself can serve as a "built-in" way of illustrating distortion, but it only functions easily when the projections are in normal, or sometimes transverse, aspects. A far better illustration is provided by the set of equilateral spherical triangles plotted on many of the colored world maps in this chapter. On the globe the triangles are alike in every way, lengths of sides, interior angles, areas, and so on, and because they neatly cover the entire globe surface one can compare the different parts of one projection as well as one projection with another. Other devices also have been used, such as spherical polygons or circles plotted in different parts of a projection, and arcs of great circles arranged strategically.

In an attempt to provide a more easily appreciated display of what a projection system does to the globe surface some authors have drawn a profile of a person's head on one projection and then mapped that same outline in the corresponding geographical positions on another projection. One can then compare the two. A major deficiency with this procedure is that the first projection always involves distortions. This flaws any comparison with reality since the profile will "look right" on whichever projection is used first.

There is considerable value in mapping a familiar figure, such as a human head, in the central sections of various world map projections. Everyone knows what a "face" should look like, and although the deformation resulting from the mapping is a complex mix of the various kinds of distortions, the overall modification of reality is readily apparent. Human faces or profiles tend to have such complex characteristics that many of the deformations are quite subtle. In order to employ a simpler and more geometric visage we use drawings of two masks, *Tragedy* and *Comedy*, derived from those worn by actors in ancient Greece, shown in Fig. 2.35. (In that period a few actors played all the parts and wore different masks to personify each role. *Tragedy* and *Comedy* were fundamental characters.)

Fig. 2.35 Comedy and tragedy masks
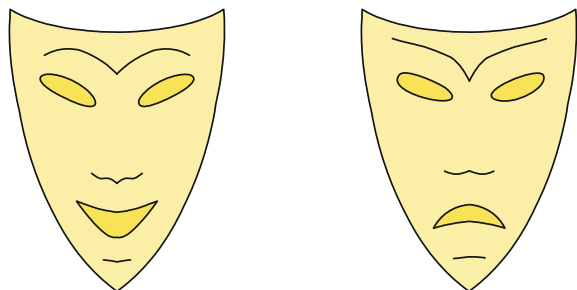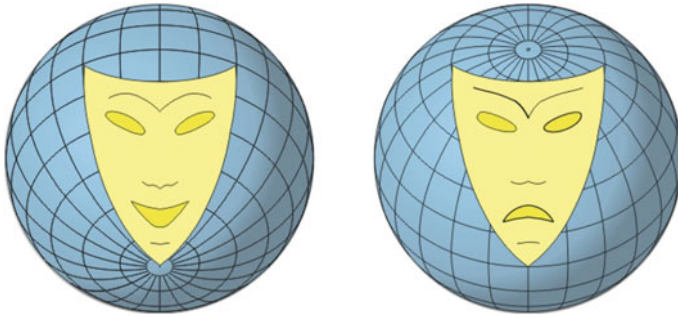
Fig. 2.36 Comedy and tragedy masks on a globe represented in orthographic projection

In order to be as realistic as possible we begin by plotting each mask on a globe (Orthographic projection), centering *Tragedy* at 45° Lat. in the northern hemisphere and *Comedy* at 45° Lat. in the southern. There is relatively little perspective distortion in the center of a globe view, and what there is is symmetrical about the center point. *Tragedy*'s chin is on the equator, and the upper tips of that mask are on the great circle formed by the meridians 90°E and 90°W of the central meridian. *Comedy*'s chin is at the South Pole, and the upper tips of that mask are on the equator.

In order that all the cartoons may be comparable they are shown at the same nominal scale. Two views of the masks on the reference globe at that scale are shown in Fig. 2.36. That scale is the same nominal scale as that of the colored world maps in earlier sections.

The plotting of the masks shown on Fig. 2.37 for the various projection systems is by computer. They are machine plotted just as would be the case were the masks continents with internal features. The masks are positioned in the central, longitudinal sections of the projections. Whatever the distortion, it is generally the least in these parts of the azimuthal and oval projections; mapping the masks farther to the right or left would add shearing. Distortion does not increase "sideways" in cylindrical projections.

2.6.2   A Final Note

To display the whole Earth on a flat map is a complicated operation. Before anything else can be done one must select a map projection to serve as a base. There are many from which to choose in each of the basic classes, and each one can be
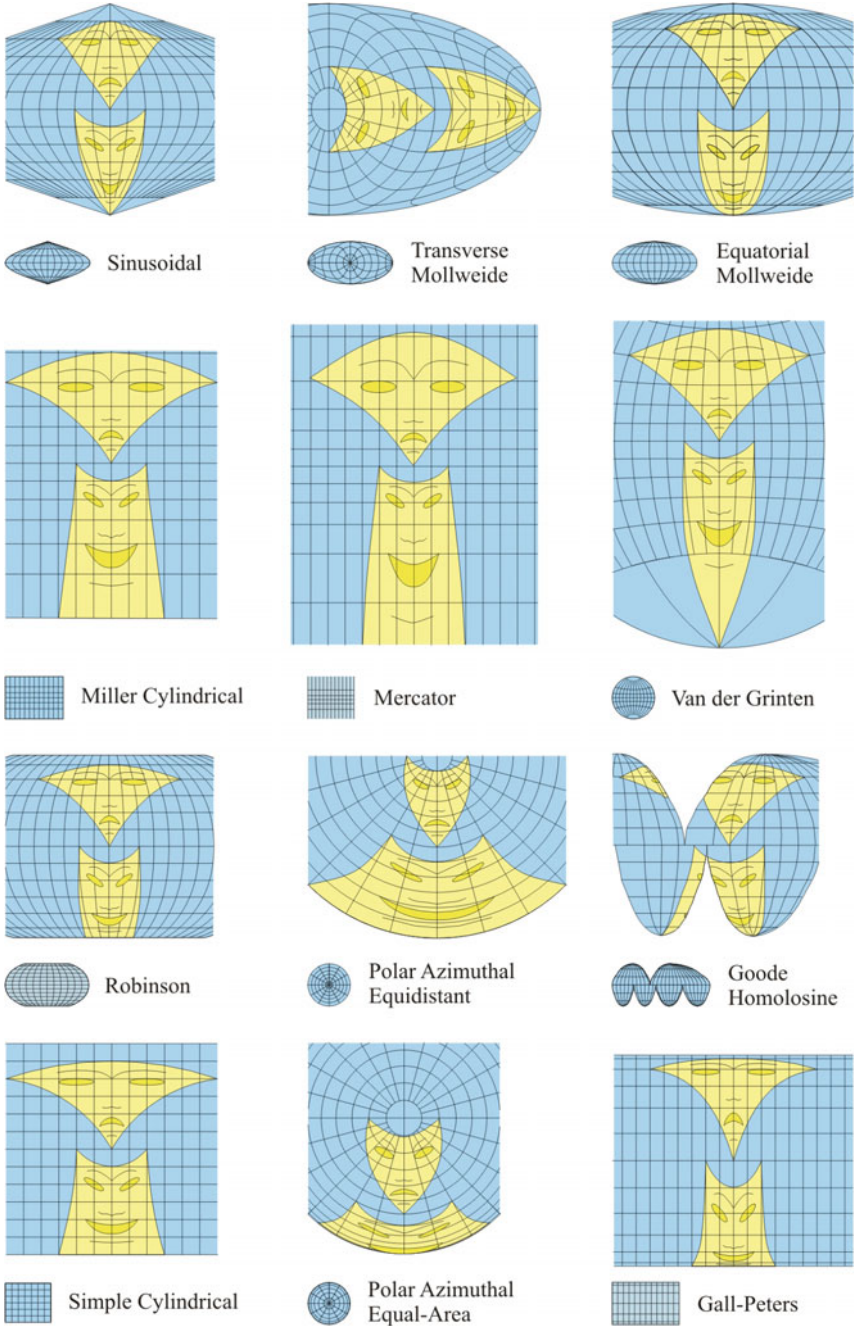
Fig. 2.37 Masks in various map projections

constructed in any desired aspect. One must settle on the necessary attributes and then adopt an appropriate distribution of the inevitable distortion.

It is not easy to make a choice, but the advantages of providing the best possible portrait of the Earth are worth the effort.