USGS
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Map Projections

A map projection is used to portray all or part of the round Earth on a flat surface. This cannot be done without some distortion.

Every projection has its own set of advantages and disadvantages. There is no "best" projection.

The mapmaker must select the one best suited to the needs, reducing distortion of the most important features.

Mapmakers and mathematicians have devised almost limitless ways to project the image of the globe onto paper. Scientists at the U.S. Geological Survey have designed projections for their specific needs — such as the Space Oblique Mercator, which allows mapping from satellites with little or no distortion.

This document gives the key properties, characteristics, and preferred uses of many historically important projections and of those frequently used by mapmakers today.

Gerardus Mercator (1512 – 1594). Frontispiece to Mercator's *Atlas sive Cosmographicae,* 1585 – 1595.
Courtesy of the Library of Congress, Rare Book Division, Lessing J. Rosenwald Collection.

U.S. Department of the Interior
U.S. Geological Survey

Map Projections

Which ones best suit your needs?

Every flat map misrepresents the surface of the Earth in some way. No map can rival a globe in truly representing the surface of the entire Earth. However, a map or parts of a map can show one or more — but never all — of the following: True directions. True distances. True areas. True shapes.

For example, the basic Mercator projection is unique; it yields the only map on which a straight line drawn anywhere within its bounds shows a particular type of direction, but distances and areas are grossly distorted near the map's polar regions.

On an equidistant map, distances are true only along particular lines such as those radiating from a single point selected as the center of the projection.

Shapes are more or less distorted on every equal-area map. Sizes of areas are distorted on conformal maps even though shapes of small areas are shown correctly. The degree and kinds of distortion vary with the projection used in making a map of a particular area. Some projections are suited for mapping large areas that are mainly north-south in extent, others for large areas that are mainly east-west in extent, and still others for large areas that are oblique to the Equator.

The scale of a map on any projection is always important and often crucial to the map's usefulness for a given purpose. For example, the almost grotesque distortion that is obvious at high latitudes on a small-scale Mercator map of the world disappears almost completely on a properly oriented large-scale Transverse Mercator map of a small area in the same high latitudes. A large-scale (1:24,000) 7.5-minute USGS Topographic Map based on the Transverse Mercator projection is nearly correct in every respect.

A basic knowledge of the properties of commonly used projections helps in selecting a map that comes closest to fulfilling a specific need.

The Globe

Directions — True.

Distances — True.

Shapes — True.

Areas — True.

Great circles — The shortest distance between any two points on the surface of the Earth can be found quickly and easily along a great circle.

Disadvantages:

Even the largest globe has a very small scale and shows relatively little detail.

Costly to reproduce and update.

Difficult to carry around.

Bulky to store.

On the globe:

Parallels are parallel and are spaced equally on meridians. Meridians and other arcs of great circles are straight lines (if looked at perpendicularly to the Earth's surface). Meridians converge toward the poles and diverge toward the Equator.

Meridians are equally spaced on the parallels, but their distances apart decreases from the Equator to the poles. At the Equator, meridians are spaced the same as parallels.

Meridians at 60° are half as far apart as parallels. Parallels and meridians cross at right angles. The area of the surface bounded by any two parallels and any two meridians (a given distance apart) is the same anywhere between the same two parallels.

The scale factor at each point is the same in any direction.

After Robinson and Sale, *Elements of Cartography* (3rd edition, John Wiley & Sons, Inc. 1969, p. 212).

Globe, as represented by Orthographic projection — equatorial aspect.

Mercator

Used for navigation or maps of equatorial regions. Any straight line on the map is a **rhumb line** (line of constant direction). **Directions** along a rhumb line are true between *any* two points on map, but a rhumb line is usually *not* the shortest distance between points. (Sometimes used with Gnomonic map on which any straight line is on a great circle and shows shortest path between two points).

Distances are true *only* along Equator, but are reasonably correct within 15° of Equator; special scales can be used to measure distances along other parallels. Two particular parallels can be made correct in scale instead of the Equator.

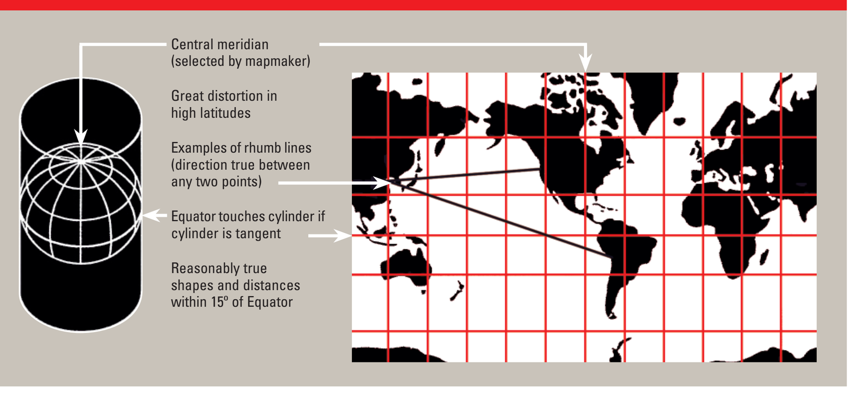
Areas and shapes of large areas are distorted. **Distortion** increases away from Equator and is extreme in polar regions. Map, however, is **conformal** in that angles and shapes within any small area (such as that shown by a USGS topographic map) are essentially true.

The map is **not** perspective, equal area, or equidistant.

Equator and other parallels are straight lines (spacing increases toward poles) and meet meridians (equally spaced straight lines) at right angles. Poles are not shown.

Presented by Mercator in 1569.

Cylindrical—Mathematically projected on a cylinder tangent to the Equator. (Cylinder may also be secant.)



Transverse Mercator

Used by USGS for many quadrangle maps at scales from 1:24,000 to 1:250,000; such maps can be joined at their edges only if they are in the same zone with one central meridian. Also used for mapping large areas that are mainly north-south in extent.

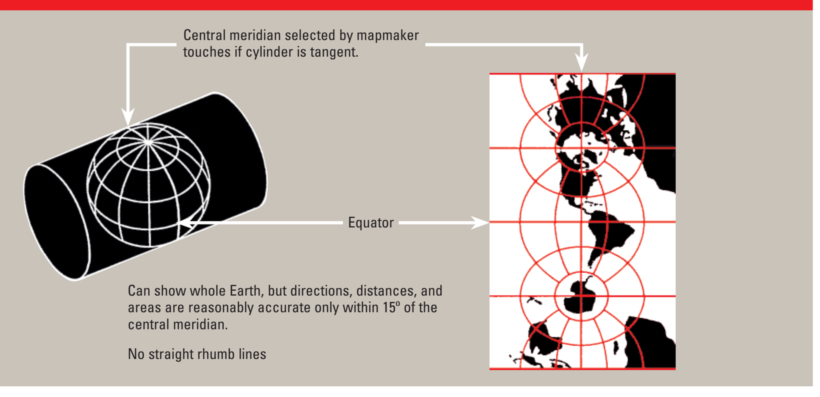
Distances are true *only* along the central meridian selected by the mapmaker or else along two lines parallel to it, but all distances, directions, shapes, and areas are reasonably accurate within 15° of the central meridian. **Distortion** of distances, directions, and size of areas increases rapidly outside the 15° band. Because the map is **conformal**, however, shapes and angles within any small area (such as that shown by a USGS topographic map) are essentially true.

Graticule spacing increases away from central meridian. Equator is straight. Other parallels are complex curves concave toward nearest pole.

Central meridian and each meridian 90° from it are straight. Other meridians are complex curves concave toward central meridian.

Presented by Lambert in 1772.

Cylindrical — Mathematically projected on cylinder tangent to a meridian. (Cylinder may also be secant.)



Oblique Mercator

Used to show regions along a **great circle** other than the Equator or a meridian, that is, having their general extent oblique to the Equator. This kind of map can be made to show as a straight line the shortest distance between any two preselected points along the selected great circle.

Distances are true *only* along the great circle (the line of tangency for this projection), or along two lines parallel to it. Distances, directions, areas, and shapes are fairly accurate within 15° of the great circle. **Distortion** of areas, distances, and shapes increases away from the great circle. It is excessive toward the edges of a world map except near the path of the great circle.

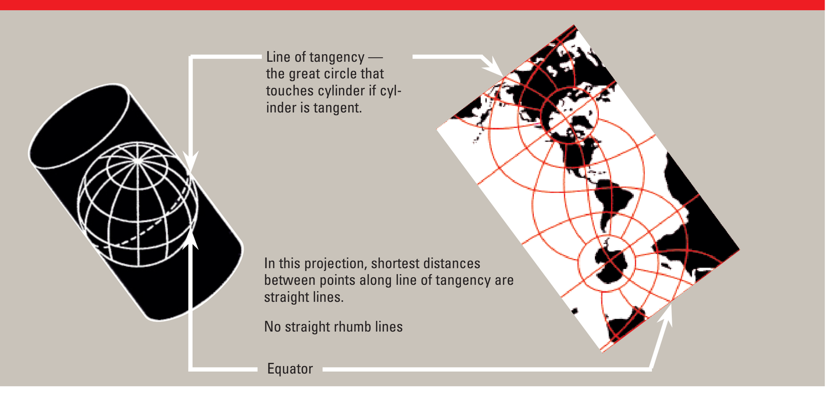
The map is **conformal**, but **not** perspective, equal area, or equidistant. Rhumb lines are curved.

Graticule spacing increases away from the great circle but conformality is retained. Both poles can be shown. Equator and other parallels are complex curves concave toward nearest pole. Two meridians 180° apart are straight lines; all others are complex curves concave toward the great circle.

Developed 1900—50 by Rosenmund, Laborde, Hotine et al.

Cylindrical—Mathematically projected on a cylinder tangent, (or secant) along any great circle but the Equator or a meridian.

Directions, distances, and areas reasonably accurate only within 15° of the line of tangency.



Space Oblique Mercator

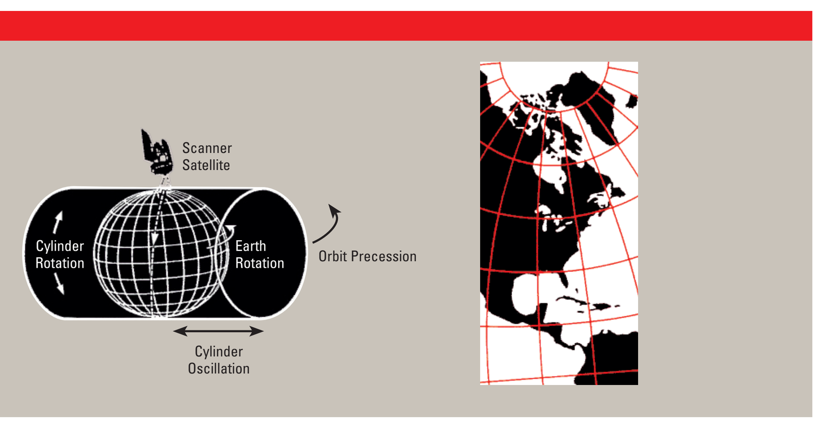
This new space-age conformal projection was developed by the USGS **for use in Landsat images** because there is no distortion along the curved ground track under the satellite. Such a projection is needed for the continuous mapping of satellite images, but it is useful only for a relatively narrow band along the ground track.

Space Oblique Mercator maps show a satellite's ground track as a curved line that is continuously true to scale as orbiting continues.

Extent of the map is defined by orbit of the satellite.

Map is basically **conformal**, especially in region of satellite scanning.

Developed in 1973—79 by A. P. Colvocoresses, J. P. Snyder, and J. L. Junkins.



Miller Cylindrical

Used to represent the entire Earth in a rectangular frame. Popular for world maps. Looks like Mercator but is not useful for navigation. Shows poles as straight lines.

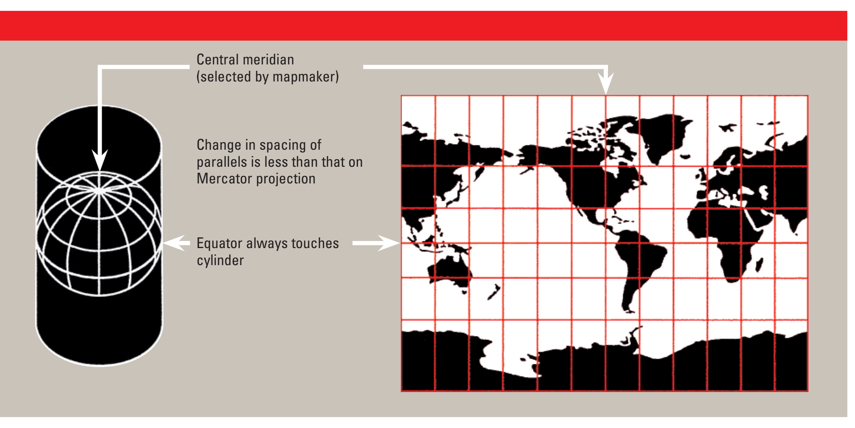
Avoids some of the scale exaggerations of the Mercator but shows neither shapes nor areas without distortion.

Directions are true only along the Equator. **Distances** are true only along the Equator. **Distortion** of distances, areas, and shapes is extreme in high latitudes.

Map is **not** equal area, equidistant, conformal or perspective.

Presented by O. M. Miller in 1942.

Cylindrical — Mathematically projected onto a cylinder tangent at the Equator.



Robinson

Uses tabular coordinates rather than mathematical formulas to make the world "look right." Better balance of **size and shape** of high-latitude lands than in Mercator, Van der Grinten, or Mollweide. Soviet Union, Canada, and Greenland truer to size, but Greenland compressed.

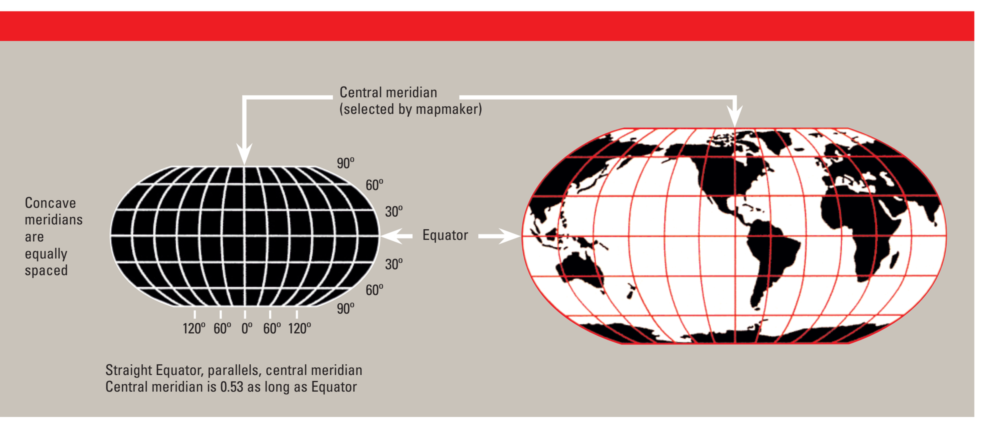
Directions true along all parallels and along central meridian. **Distances** constant along Equator and other parallels, but scales vary. **Scale** true along 38° N. & S., constant along any given parallel, same along N. & S. parallels that are the same distance from Equator. **Distortion:** All points have some. Very low along Equator and within 45° of center. Greatest near the poles.

Not conformal, equal area, equidistant, or perspective.

Used in *Goode's Atlas*, adopted for *National Geographic's* world maps in 1988, appears in growing number of other publications, may replace Mercator in many classrooms.

Presented by Arthur H. Robinson in 1963.

Pseudocylindrical or orthophanic ("right appearing") projection.



Sinusoidal Equal Area

Used frequently in atlases to show distribution patterns. Used by the USGS to show prospective hydrocarbon provinces and sedimentary basins of the world. Has been used for maps of Africa, South America, and other large areas that are mainly north-south in extent.

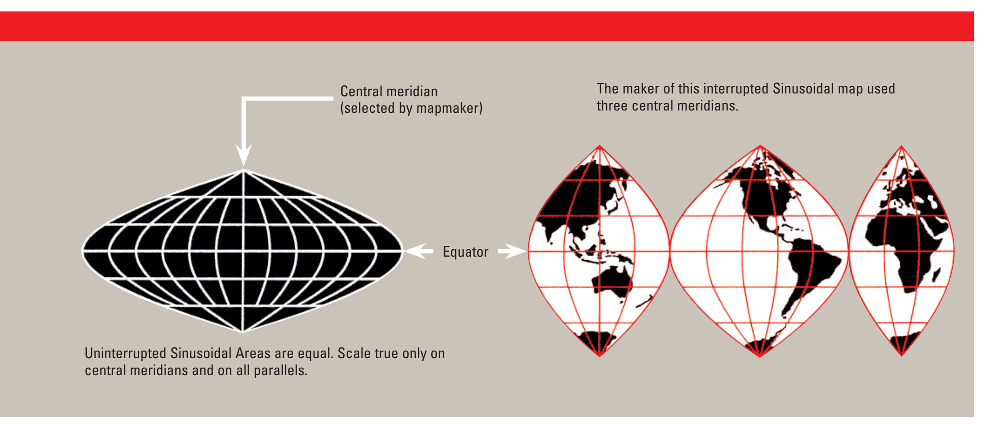
An easily plotted equal-area projection for world maps. May have a single central meridian or, in interrupted form, several central meridians.

Graticule spacing retains property of equivalence of area. **Areas** on map are proportional to same areas on the Earth. **Distances** are correct along all parallels and the central meridian(s). **Shapes** are increasingly distorted away from the central meridian(s) and near the poles.

Map is **not** conformal, perspective, or equidistant.

Used by Cossin and Hondius, beginning in 1570. Also called the Sanson-Flamsteed.

Pseudocylindrical — Mathematically based on a cylinder tangent to the Equator.



Orthographic

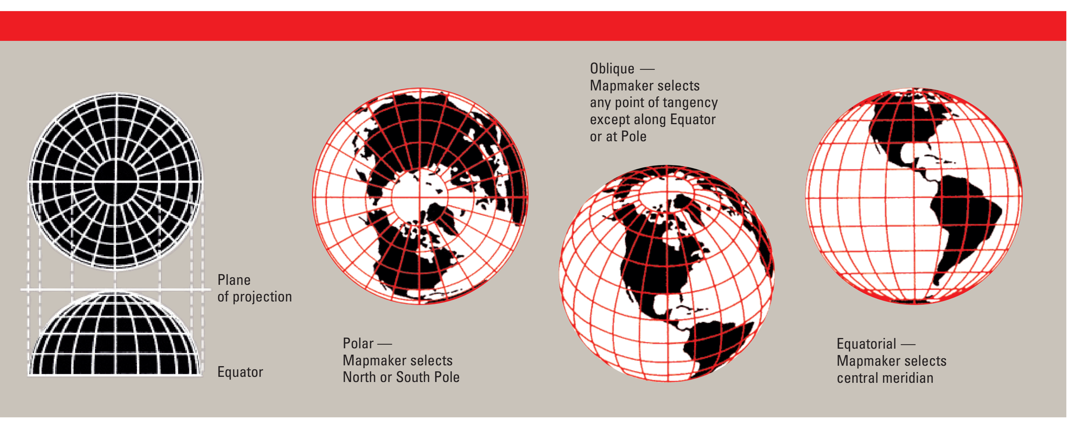
Used for perspective views of the Earth, Moon, and other planets. The Earth appears as it would on a photograph from deep space. Used by USGS in the *National Atlas of the United States of America*™.

Directions are true only from center point of projection. **Scale** decreases along all lines radiating from center point of projection. Any straight line through center point is a great circle. **Areas and shapes** are distorted by perspective; distortion increases away from center point.

Map is **perspective** but **not** conformal or equal area. In the polar aspect, distances are true along the Equator and all other parallels.

The Orthographic projection was known to Egyptians and Greeks 2,000 years ago.

Azimuthal — Geometrically projected onto a plane. Point of projection is at infinity.



Stereographic

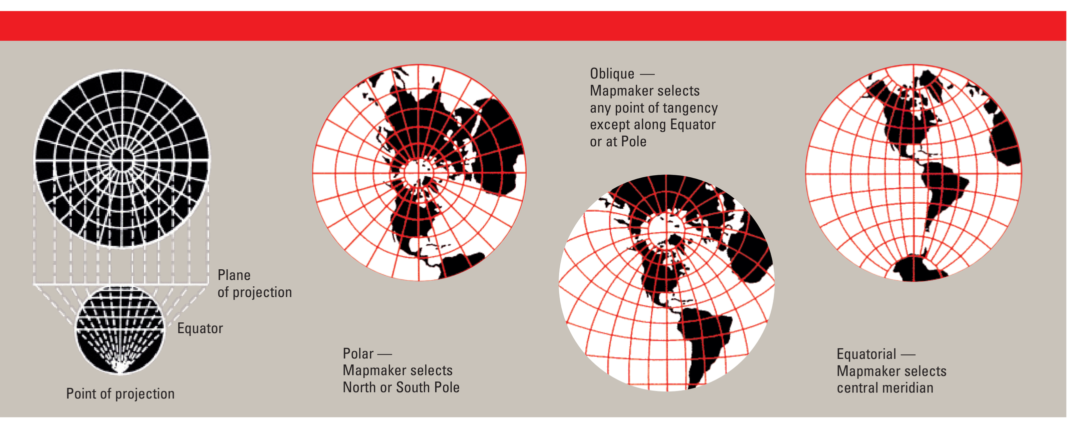
Used by the USGS for maps of Antarctica and American Geographical Society for Arctic and Antarctic maps. May be used to map large continent-sized areas of similar extent in all directions. Used in geophysics to solve spherical geometry problems. Polar aspects used for topographic maps and charts for navigating in latitudes above 80°.

Directions true *only* from center point of projection. **Scale** increases away from center point. Any straight line through center point is a **great circle**. **Distortion** of areas and large shapes increases away from center point.

Map is **conformal** and **perspective** but **not** equal area or equidistant.

Dates from 2nd century B.C. Ascribed to Hipparchus.

Azimuthal — Geometrically projected on a plane. Point of projection is at surface of globe opposite the point of tangency.



Gnomonic

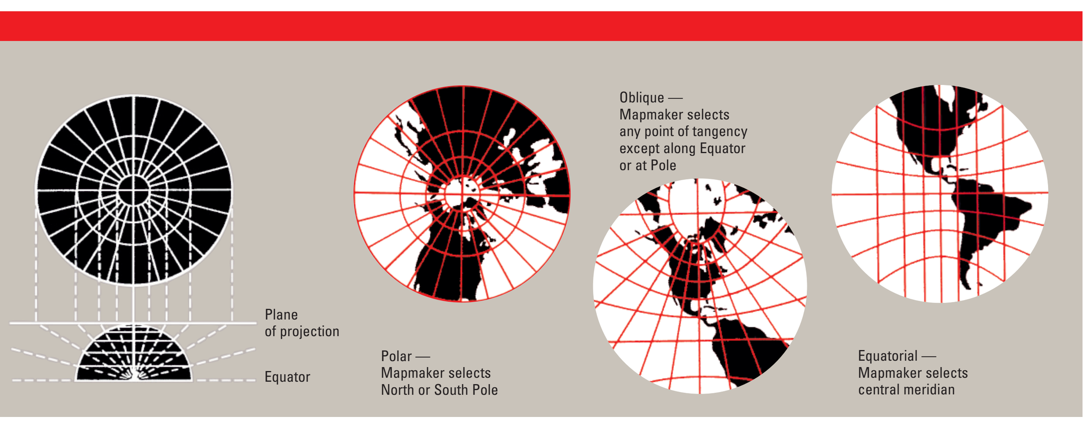
Used along with the Mercator by some navigators to find the shortest path between two points. Used in seismic work because seismic waves tend to travel along great circles.

Any straight line drawn on the map is on a **great circle**, but **directions** are true *only* from center point of projection. **Scale** increases very rapidly away from center point. **Distortion** of shapes and areas increases away from center point.

Map is perspective (from the center of the Earth onto a tangent plane) but **not** conformal, equal area, or equidistant.

Considered to be the oldest projection. Ascribed to Thales, the father of abstract geometry, who lived in the 6th century B.C.

Azimuthal — Geometrically projected on a plane. Point of projection is the center of a globe.

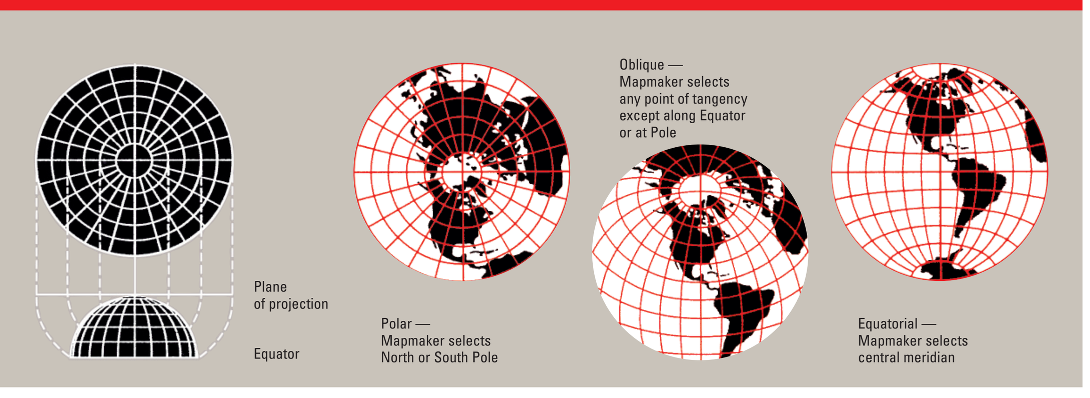


Azimuthal Equidistant

Used by USGS in the *National Atlas of the United States of America*™ and for large-scale mapping of Micronesia. Useful for showing airline distances from center point of projection. Useful for seismic and radio work. Oblique aspect used for atlas maps of continents and world maps for radio and aviation use. Polar aspect used for world maps, maps of polar hemispheres, and United Nations emblem.

Distances and **directions** to *all* places true *only* from center point of projection. Distances correct between points along straight lines through center. All other distances incorrect. Any straight line drawn through center point is on a **great circle**. **Distortion** of areas and shapes increases away from center point.

Azimuthal — Mathematically projected on a plane tangent to any point on globe. Polar aspect is tangent only at pole.



Lambert Azimuthal Equal Area

Used by the USGS in its National Atlas and Circum-Pacific Map Series. Suited for regions extending equally in all directions from center points, such as Asia and Pacific Ocean.

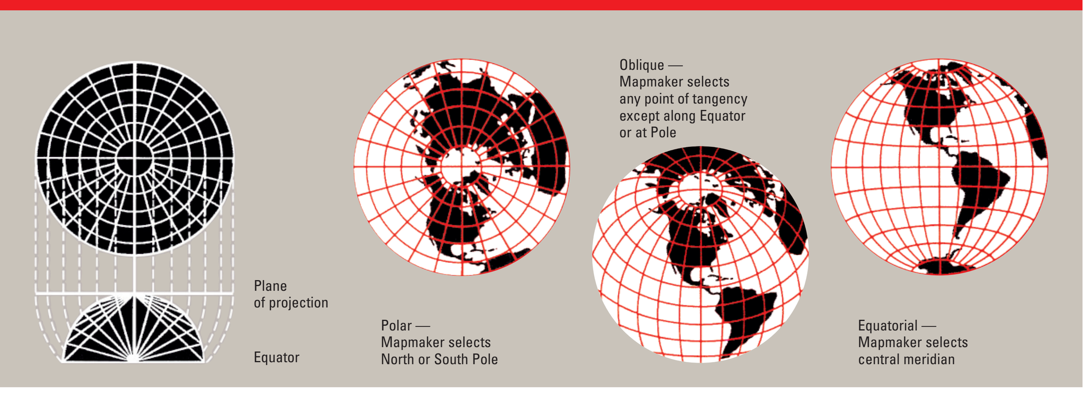
Areas on the map are shown in true proportion to the same areas on the Earth. Quadrangles (bounded by two meridians and two parallels) at the same latitude are uniform in area.

Directions are true *only* from center point. **Scale** decreases gradually away from center point. **Distortion** of shapes increases away from center point. Any straight line drawn through center point is on a **great circle**.

Map is equal area but **not** conformal, perspective, or equidistant.

Presented by Lambert in 1772.

Azimuthal — Mathematically projected on a plane tangent to any point on globe. Polar aspect is tangent only at pole.



Albers Equal Area Conic

Used by USGS for maps showing the conterminous United States (48 states) or large areas of the United States. Well suited for large countries or other areas that are mainly east-west in extent and that require equal-area representation. Used for many thematic maps.

Maps showing adjacent areas can be joined at their edges only if they have the same standard parallels (parallels of no distortion) and the same scale.

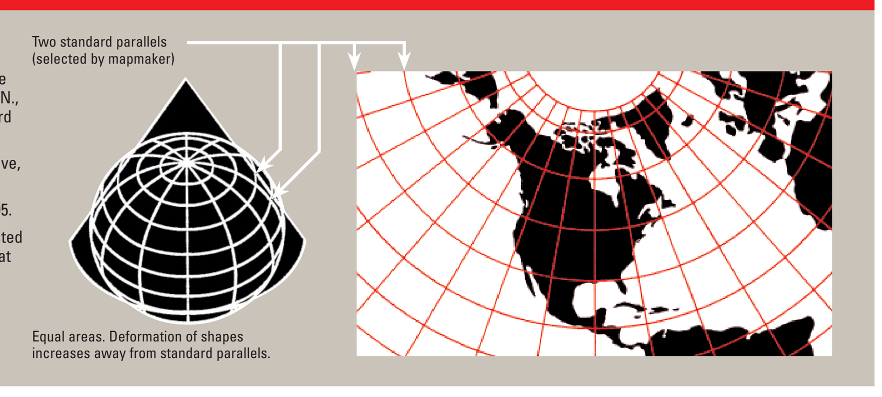
All areas on the map are proportional to the same areas on the Earth. **Directions** are reasonably accurate in limited regions. **Distances** are true on both standard parallels. Maximum scale error is 1¼% on map of conterminous States with standard parallels of 29½°N. and 45½°N. **Scale** true only along standard parallels.

USGS maps of the conterminous 48 States, if based on this projection, have standard parallels 29½°N. and 45½°N. Such maps of Alaska use standard parallels 55°N. and 65°N., and maps of Hawaii use standard parallels 8°N. and 18°N.

Map is **not** conformal, perspective, or equidistant.

Presented by H. C. Albers in 1805.

Conic — Mathematically projected on a cone conceptually secant at two standard parallels.



Lambert Conformal Conic

Used by USGS for many 7.5- and 15-minute topographic maps and for the State Base Map series. Also used to show a country or region that is mainly east-west in extent.

One of the most widely used map projections in the United States today. Looks like the Albers Equal Area Conic, but graticule spacings differ.

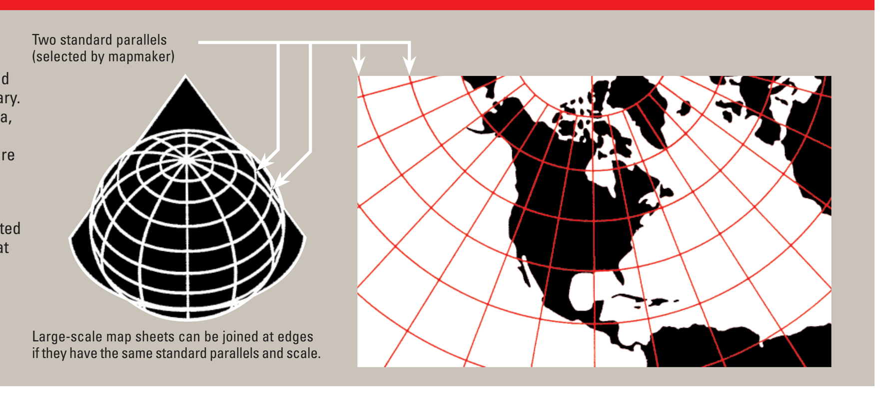
Retains conformality. **Distances** true *only* along standard parallels; reasonably accurate elsewhere in limited regions. **Directions** reasonably accurate. **Distortion** of shapes and areas minimal at, but increases away from standard parallels. **Shapes** on large-scale maps of small areas essentially true.

Map is **conformal** but **not** perspective, equal area, or equidistant.

For USGS Base Map series for the 48 conterminous States, standard parallels are 33°N. and 45°N. (maximum scale error for map of 48 States is 2½ %). For USGS Topographic Map series (7.5- and 15-minute), standard parallels vary. For aeronautical charts of Alaska, they are 55°N. and 65°N.; for the *National Atlas of Canada*, they are 49°N. and 77°N.

Presented by Lambert in 1772.

Conic — Mathematically projected on a cone conceptually secant at two standard parallels.



Equidistant Conic (Simple Conic)

Used in atlases to show areas in the middle latitudes. Good for showing regions within a few degrees of latitude and lying on one side of the Equator. (One example, the Kavraisky No. 4, is an Equidistant Conic projection in which standard parallels are chosen to minimize overall error.)

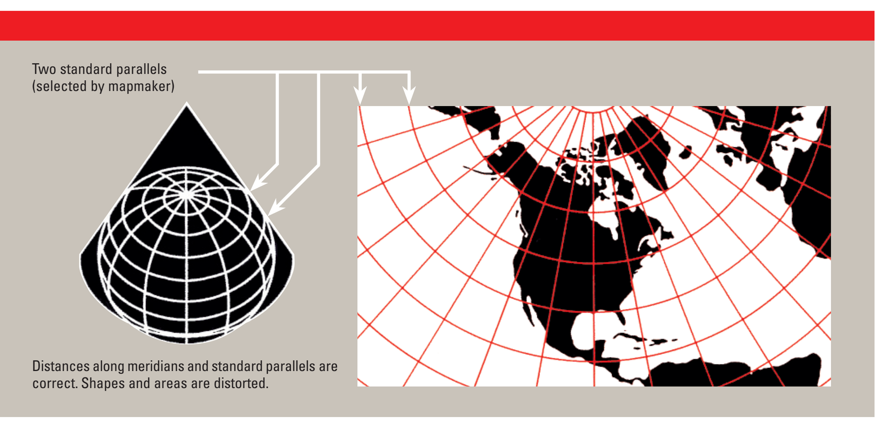
Distances are true *only* along all meridians and along one or two standard parallels.

Directions, shapes and areas are reasonably accurate, but **distortion** increases away from standard parallels.

Map is **not** conformal, perspective, or equal area, but a compromise between Lambert Conformal Conic and Albers Equal Area Conic.

Prototype by Ptolemy, 150 A.D. Improved by De l'Isle about 1745.

Conic — Mathematically projected on a cone tangent at one parallel or conceptually secant at two parallels.



Polyconic

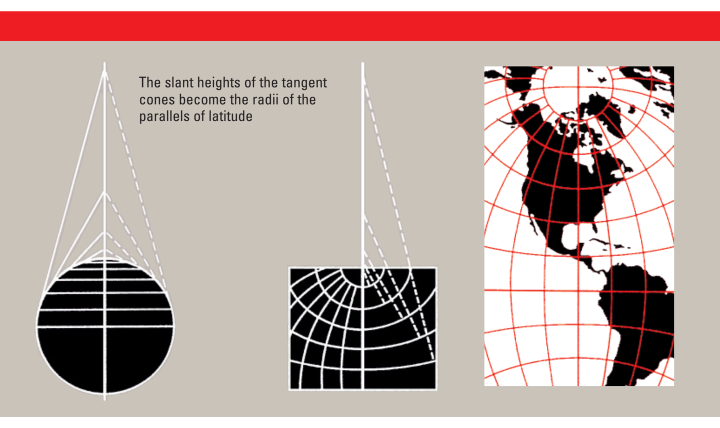
Used almost exclusively for large-scale mapping in the United States until the 1950's. Now nearly obsolete, and no longer used by USGS for new plotting in its Topographic Map series. Best suited for areas with a north-south orientation.

Directions are true *only* along central meridian. **Distances** are true only along each parallel and along central meridian. **Shapes and areas** true *only* along central meridian. **Distortion** increases away from central meridian.

Map is a compromise of many properties. It is **not** conformal, perspective, or equal area.

Apparently originated about 1820 by Hassler.

Conic — Mathematically based on an infinite number of cones tangent to an infinite number of parallels.



Bipolar Oblique Conic Conformal

This "tailor-made" projection is **used** to show one or both of the American continents. Outlines in the projection diagram represent areas shown on USGS Basement and Tectonic Maps of North America.

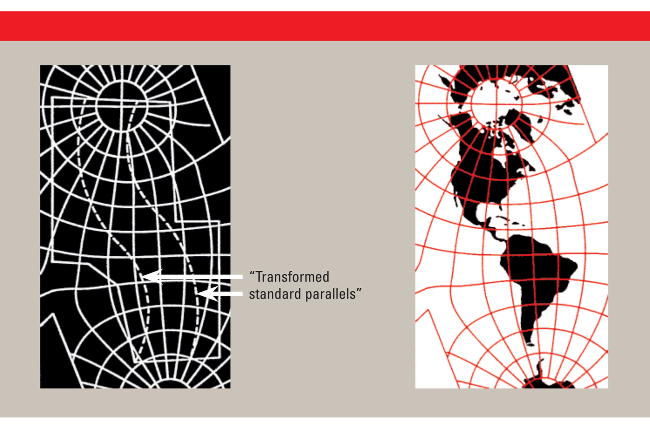
Scale is true along two lines ("transformed standard parallels") that do not lie along any meridian or parallel. Scale is compressed between these lines and expanded beyond them. Scale is generally good but error is as much as 10% at the edge of the projection as used.

Graticule spacing increases away from the lines of true scale but retains the property of conformality except for a small deviation from conformality where the two conic projections join.

Map is conformal but **not** equal area, equidistant, or perspective.

Presented by O. M. Miller and W. A. Briesemeister in 1941.

Conic — Mathematically based on two cones whose apexes are 104° apart and which conceptually are obliquely secant to the globe along lines following the trend of North and South America.



Summary

● = Yes
○ = Partly

Projection	Type	Properties: Conformal	Equal Area	Equidistant	True Direction	Perspective	Compromise	Straight Rhumbs	Suitable for Mapping: World	Hemisphere	Continent/Ocean	Region/Sea	Medium Scale	Large Scale	General Use: Topographic Maps	Geological Maps	Thematic Maps	Presentations	Navigation	USGS Maps
Globe	Sphere	●	●	●	●				●								●	●		
Mercator	Cylindrical	●			○			●	○			●			●	●			●	●
Transverse Mercator	Cylindrical	●									●	●	●	●	●	●				●
Oblique Mercator	Cylindrical	●									●	●	●	●	●					●
Space Oblique Mercator	Cylindrical	●												●	●					●
Miller Cylindrical	Cylindrical						●		●								●			●
Robinson	Pseudocylindrical						●		●								●	●		
Sinusoidal Equal Area	Pseudocylindrical		●	○					●		●						●			●
Orthographic	Azimuthal				○	●				○										●
Stereographic	Azimuthal	●			○	●				●	●	●	●	●	●	●			●	●
Gnomonic	Azimuthal				○	●						○						●	●	
Azimuthal Equidistant	Azimuthal			○	○				○	●	●	●		○	●					●
Lambert Azimuthal Equal Area	Azimuthal		●		○					●	●	●					●	●		●
Albers Equal Area Conic	Conic		●								●	●	●				●	●		●
Lambert Conformal Conic	Conic	●			○						●	●	●	●	●	●		●	●	●
Equidistant Conic (Simple Conic)	Conic			○							●	●								
Polyconic	Conic			○			●						○	○	●					●
Bipolar Oblique Conic Conformal	Conic	●									●					●				●

All above projections (except Robinson) are explained in detail in Map Projections — A Working Manual, John P. Snyder, U. S. Geological Survey, Professional Paper 1395 (Washington: USGPO, 1987, 383 pp.)

General Notes:

Azimuth — The angle measured in degrees between a base line radiating from a center point and another line radiating from the same point. Normally, the base line points North, and degrees are measured clockwise from the base line.

Aspect — Individual azimuthal map projections are divided into three aspects: the polar aspect which is tangent at the pole, the equatorial aspect which is tangent at the Equator, and the oblique aspect which is tangent anywhere else. (The word "aspect" has replaced the word "case" in the modern cartographic literature.)

Conformality — A map projection is conformal when at any point the scale is the same in every direction. Therefore, meridians and parallels intersect at right angles and the shapes of very small areas and angles with very short sides are preserved. The size of most areas, however, is distorted.

Developable surface — A developable surface is a simple geometric form capable of being flattened without stretching. Many map projections can then be grouped by a particular developable surface: cylinder, cone, or plane.

Equal areas — A map projection is equal area if every part, as well as the whole, has the same area as the corresponding part on the Earth, at the same reduced scale. No flat map can be both equal area and conformal.

Equidistant — Equidistant maps show true distances only from the center of the projection or along a special set of lines. For example, an Azimuthal Equidistant map centered at Washington shows the correct distance between Washington and any other point on the projection. It shows the correct distance between Washington and San Diego and between Washington and Seattle. But it does not show the correct distance between San Diego and Seattle. No flat map can be both equidistant and equal area.

Graticule — The graticule is the spherical coordinate system based on lines of latitude and longitude.

Great circle — A circle formed on the surface of a sphere by a plane that passes through the center of the sphere. The Equator, each meridian, and each other full circumference of the Earth forms a great circle. The arc of a great circle shows the shortest distance between points on the surface of the Earth.

Linear scale — Linear scale is the relation between a distance on a map and the corresponding distance on the Earth. Scale varies from place to place on every map. The degree of variation depends on the projection used in making the map.

Map projection — A map projection is a systematic representation of a round body such as the Earth on a flat (plane) surface. Each map projection has specific properties that make it useful for specific purposes.

Rhumb line — A rhumb line is a line on the surface of the Earth cutting all meridians at the same angle. A rhumb line shows true direction. Parallels and meridians, which also maintain constant true directions, may be considered special cases of the rhumb line. A rhumb line is a straight line on a Mercator projection. A straight rhumb line does not show the shorter distance between points unless the points are on the Equator or on the same meridian.

U.S. Department of the Interior
U.S. Geological Survey

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