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U.S. Geological Survey Circular 982

Map Projections Used for Large-Scale Quadrangles by the U.S. Geological Survey

Supersedes USGS Circular 57, State Coordinates and Polyconic Maps, dated May 1949, from which some portions are adapted

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By John P. Snyder

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MAP PROJECTIONS USED FOR LARGE-SCALE QUADRANGLES BY THE U.S. GEOLOGICAL SURVEY

By John P. Snyder

After the U.S. Geological Survey (USGS) was created in 1879, detailed large-scale mapping of the country soon became one of its primary objectives. Until the late 1950's, only the Polyconic projection was used for the primary USGS mapping product, i.e., large-scale quadrangle maps. In the 1950's, the projection for most new quadrangles was changed to the Lambert Conformal Conic or the Transverse Mercator, which had been adopted by the Coast and Geodetic Survey in the 1930's for the State Plane Coordinate System (SPCS). The development of standardized zones based upon the Universal Transverse Mercator (UTM) grid and projection system led to USGS use of this form of the Transverse Mercator projection for some more recent quadrangles. Although one SPCS zone in Alaska is based on the Oblique Mercator projection, this projection is not used for the USGS quadrangles.

THE EARTH AS AN ELLIPSOID

For all large-scale quadrangle mapping by the USGS, the Earth is treated as an ellipsoid or spheroid, a sphere flattened by about 1 part in 300. All descriptions below refer to the ellipsoidal forms of the three map projections used. The USGS is currently undertaking a change in the datum upon which the mapping occurs. This involves a change in the dimensions of the ellipsoid as well as a change of the position of its polar and equatorial axes with respect to the continental land masses. A shift from one datum to another results in a slight change of latitude and longitude for all points on a map, as well as a different change in the positions of grid coordinates. For this reason, the notation on USGS quadrangles stating "North American Datum 1927" or "1983" is one of the essential parameters of the map projection that defines these maps.

CONFORMAL MAP PROJECTIONS

The two most important properties that may be preserved with map projections are area and shape, but no one projection can preserve both. Area-preserving projections are called equal-area or equivalent and are used for many geographical applications. Most modern topographic mapping throughout the world is plotted using conformal map projections. On a conformal map, each small element is basically correct in shape. Angles at each point are correct, and consequently the local scale in every direction around any one point is constant, so the map user can measure distance and direction between near points with a minimum of difficulty. Conformal maps may also be prepared in practice by fitting together small pieces of other conformal maps that have been enlarged or reduced, whereas pieces of

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nonconformal projections would require reshaping as well. Because there is no angular distortion, all meridians intersect parallels at right angles on a conformal projection, just as they do on the Earth. Standard lines may be specified for a conformal map to eliminate scale and area distortion along these lines and to minimize distortion elsewhere. On conformal maps the size of USGS large-scale quadrangles, the distortion of scale and area is very small.

THE POLYCONIC PROJECTION

About 1820, the easily constructed Polyconic projection began to be promoted as the basis of large-scale mapping. The USGS used this projection for the earliest quadrangles, changing only in the 1950's to other projections, although relabeling the map legend has lagged considerably behind the change. The Polyconic is neither conformal nor does it preserve correct area. For 7.5- and 15-minute quadrangles, however, the distortion is insignificant. Along the straight central meridian, the projection is free of distortion. Each parallel is also true to scale, but the other meridians are too long, and constantly change scale.

The parallels of latitude are circular arcs spaced at their true distances along the central meridian, but with radii equal to the length of the element of a cone tangent at the particular parallel. The projection receives its name from the fact that each cone is different (fig. 1). Meridians are marked on each parallel at their true distances from the central meridian, but the meridians are theoretically complex curves connecting these points. Lines of constant scale in a north-south direction run roughly parallel to the central meridian, but they are curved.

The location of the central meridian on a Polyconic quadrangle is normally at the center of the map. Frequently, however, a bounding meridian has been used as the central meridian. For 15- and 7.5-minute quadrangles, the difference resulting from positioning the central meridian in the center or on the edge is negligible. Furthermore, because of the limited coverage, the meridians were drawn straight rather than curved. In any case, adjacent quadrangles match perfectly from north to south, and because of the straight meridians they also match from east to west, but they cannot be assembled beyond a single row or single column without gaps (fig. 2). The projection is not recommended for maps of considerable east-west extent nor for any new maps in view of other projections available.

THE TRANSVERSE MERCATOR PROJECTION

The most frequently used conformal projection for large-scale mapping is the Transverse Mercator. The Transverse Mercator is considered a cylindrical projection because the Earth may be conceptually (but not geometrically) projected by wrapping a cylinder around a globe so that the cylinder is tangent along a meridian, or secant along lines parallel to this meridian (fig. 1). When the meridians and parallels are properly placed on this cylinder, and the cylinder is cut along a line perpendicular to this meridian, unrolled, and laid flat, the Transverse Mercator projection results. The central meridian is a straight line. All other meridians and parallels on U.S. quadrangles are theoretically complex curves, but are practically straight segments. The central meridian has a constant scale, but this is usually reduced from the nominal map scale to balance errors in measurement over the rest of the map. The lines of constant scale are nearly straight lines parallel to the central meridian. When the scale factor along the central meridian is reduced, there are two lines of true scale that are symmetrical with respect to the central meridian. The projection was developed by Lambert and later Gauss during the late 18th and early 19th centuries, but it was almost ignored until the 20th century, when it was adopted for much of the topographic mapping in Europe under the name

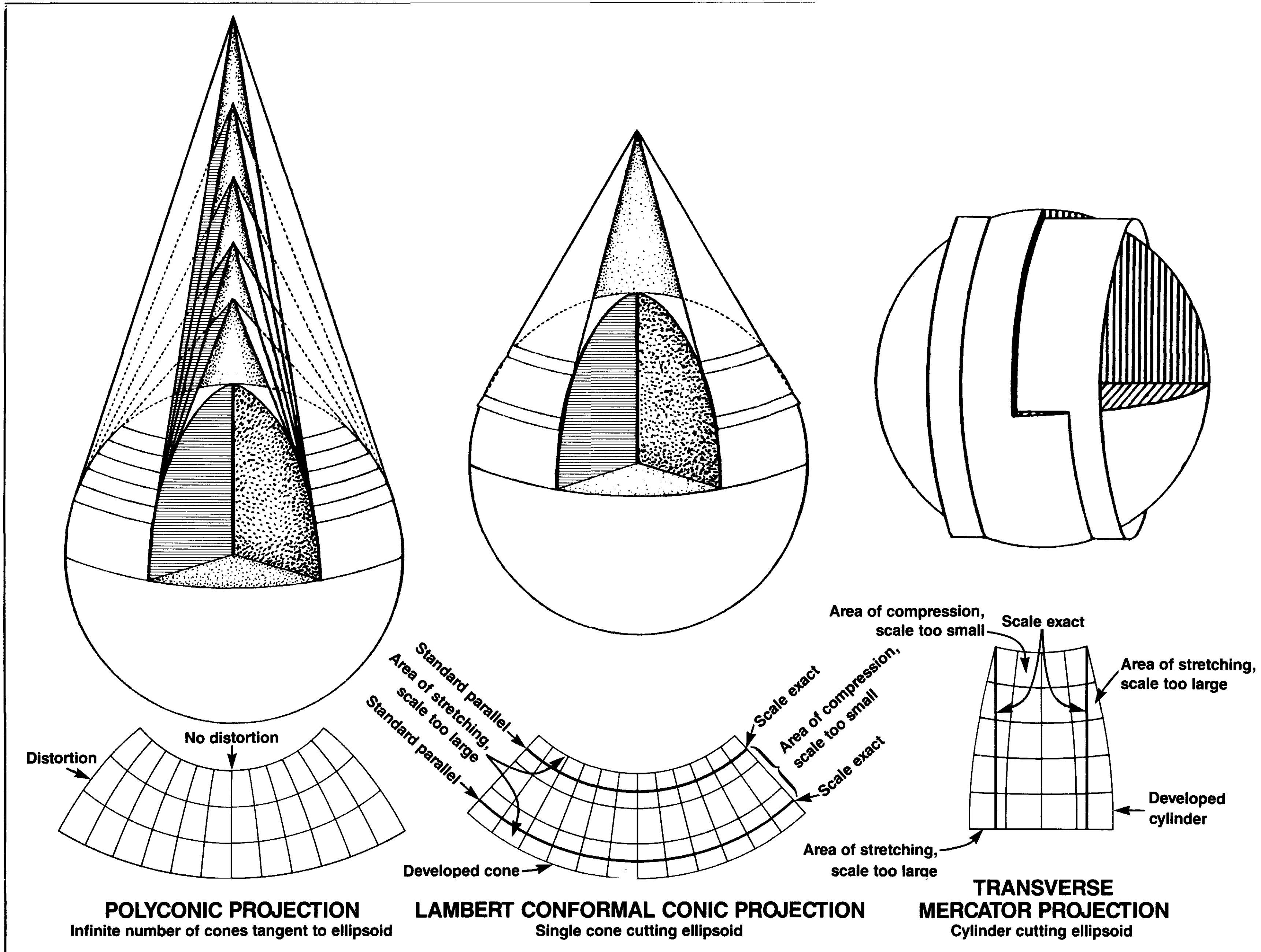

Figure 1.--Diagrams showing development of respective projections and type and location of principal distortions.

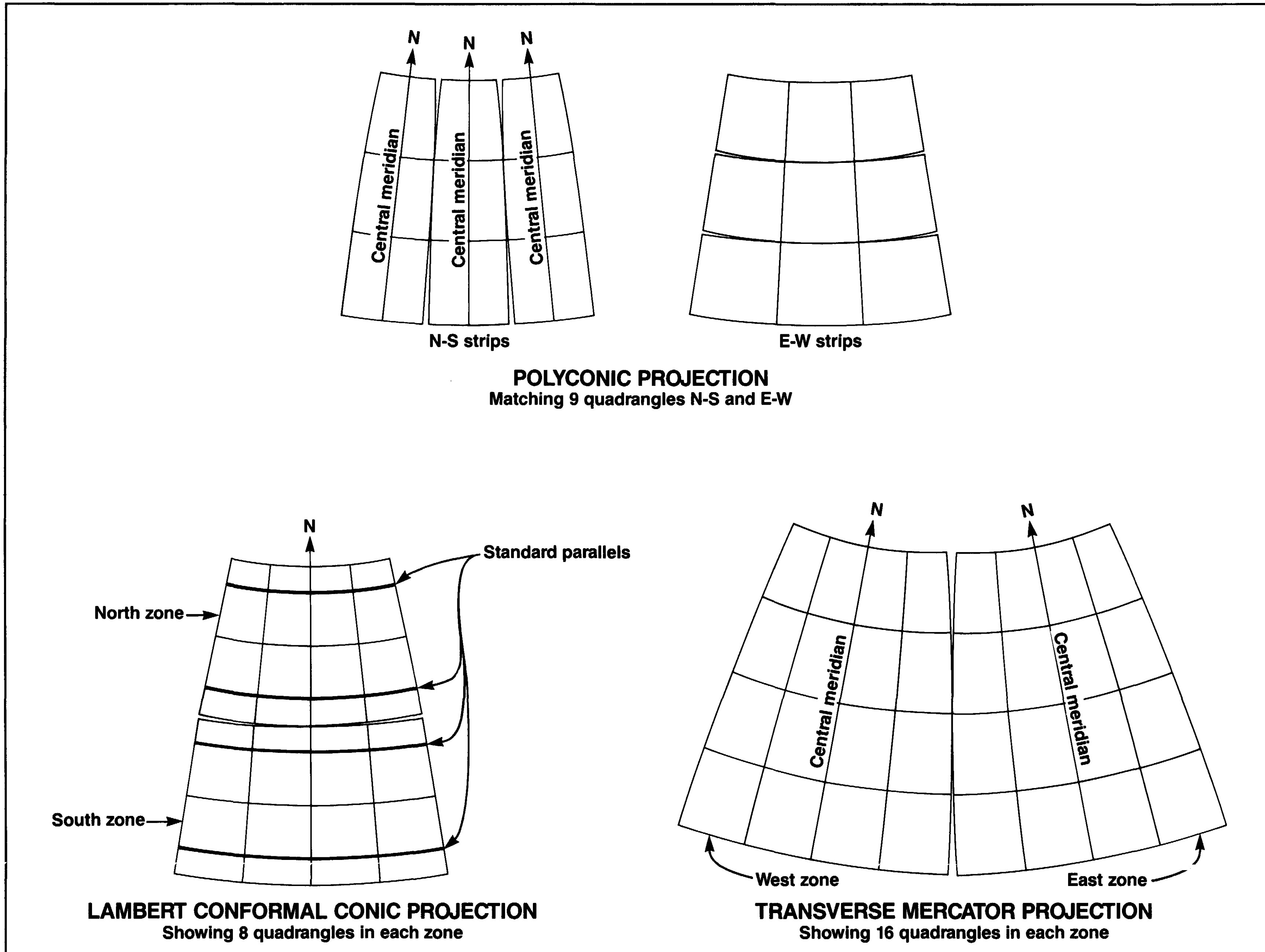

Figure 2.--Diagrams showing matching of quadrangle sheets and zones on the respective projections.

Gauss-Krüger. In the United States, the Transverse Mercator projection was adopted for the SPCS of States that are predominantly north and south in extent and for the UTM projection and grid system. The UTM has two special restrictions: (1) the Earth is divided into 60 zones, each 6° of longitude wide, with the central meridians placed at every sixth meridian beginning with the 177th West; and (2) the central meridian scale factor is 0.9996. (There are minor exceptions.)

When the USGS stopped using the Polyconic projection for large-scale quadrangle maps, the Transverse Mercator was adopted for maps of regions where it was used for the SPCS, except that in Alaska, the UTM is used for the 15-minute quadrangles. The UTM is also used for some recent 1:100,000-scale mapping in the conterminous 48 States. In the SPCS, each zone follows county boundaries, and the central meridian and its scale are selected to restrict scale variation over the zone to one part in ten thousand. The central-meridian scale factors, which change between zones, vary from 1.0 to 0.9999. The USGS uses the predominant zone for the projection of quadrangles that cross county boundaries.

The discrepancies in measurements between the Polyconic and the Transverse Mercator forms of the same 7.5- or 15-minute quadrangle depend especially upon the distance of the quadrangle from the central meridian of the zone. The Transverse Mercator quadrangles can be mosaicked for the entire zone (fig. 2).

THE LAMBERT CONFORMAL CONIC PROJECTION

Nearly all the States predominantly east and west in extent use the Lambert Conformal Conic as the projection for the SPCS. It was therefore adopted by the USGS for post-1950 quadrangle mapping of these areas. On the Lambert Conformal Conic projection, the Earth may be conceptually (but not geometrically) projected onto a cone made tangent to one or secant to two standard parallels on the globe, with its apex along the polar axis (fig. 1). The cone is then cut open along a meridian and laid flat.

This projection, presented by Lambert in 1772, maps parallels as concentric circular arcs and the meridians as equally spaced straight radii of those circles. One pole is at the center of the circles, while the other pole is at infinity. There are usually two standard parallels, which have no scale distortion. (It is possible to have only one standard parallel, but this does not apply to USGS maps.) The scale is too small between the two standard parallels, and too large north and south of them.

Each zone of the SPCS has its own standard parallels, which fall within the zone near the northern and southern limits. These are the parameters used for USGS quadrangles that have been produced on this projection; thus, all quadrangles edgematch within the zone (fig. 2).

COMPARISON BETWEEN QUADRANGLES OF DIFFERENT PROJECTIONS

For a region only 7.5 or 15 minutes in extent, the differences between quadrangles cast on the Polyconic, Transverse Mercator, or Lambert Conformal Conic projections are almost negligible if the quadrangles are close to the central meridians or standard parallels of each, except for the scale adjustment to the central meridians of the Transverse Mercator zones. The differences are still small but measurable if one of the quadrangles is near the edge of a zone.

DISTORTION OF THE MAP MATERIAL; GRID OVERLAYS

Of much greater practical significance than the difference between projections on large-scale quadrangles is the fact that distortions may be developed in a map through the physical instability of the medium on which it is drawn or printed. It is well known that paper will shrink or expand with changes in the surrounding atmospheric conditions, as well as from other causes. The change in dimensions of any sheet of paper will normally not be the same in all directions, and changes of shape as well as of size may result. These changes can be so great as to obliterate completely the theoretical distortions and scale changes resulting from the map projection. It is not unusual for a dimensional change as great as 1/8 inch to occur in a single quadrangle map sheet on map paper. Under such conditions, it is impossible to assemble perfectly a number of adjoining sheets, each with its own unpredictable paper distortion, regardless of the projection on which the maps were prepared.

Special plastic films are available in which distortions can be reduced or controlled, and such improved materials should be used, when feasible, in the preparation of maps. Unless materials of exceptional stability are employed, it may be assumed that the theoretical differences between the projections for large-scale mapping will always be less than the probable distortions of the paper or other materials on which the map may be produced. Since the late 1950's, large-scale USGS maps have been prepared on stable-base materials, and should be obtained in this form for precision mapping.

Since paper maps will continue to be commonly used, the use of gridlines on maps is especially helpful in overcoming the effects of expansion and contraction. A square grid based on UTM coordinates for every 1,000 meters is typically shown on 7.5-minute USGS quadrangles. Since this grid expands with the paper, coordinates of intermediate points may be determined with a high degree of precision, and then converted to geographic coordinates or to distances from other points.

For more information about the use of and calculations involving these projections, see Snyder (1983) and Thompson (1981).

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