MAPPING EXERCISE
Map Projections

All too often emphasis in map production is placed on becoming operational with GIS software while neglecting basic, yet important, map design principals. For many mapmakers, one of the most neglected elements of map compilation is the map projection. Use of an appropriate map projection is essential in mapping as it is the foundation upon which the map is built. It quite literally, shapes the map.

At its core, a map projection is nothing more than a transformation of the three-dimensional Earth to a two-dimensional representation such as a piece of paper or computer display. The transformation may use a geometric form (cylinder, plane or cone) or mathematics. Regardless of the method of transformation, no map projections can be formed without distortion taking place. There are hundreds of map projections available to the cartographer and distortion will differ according to how the projection is created.

There are four families of map projections—azimuthal (planar), cylindrical, conic, and mathematical—and there are several individual projections belonging to each family. In the **azimuthal** family, the grid of a **generating globe** (a model based on spherical, ellipsoidal, or geoidal representations of the Earth) is projected onto a plane. **Cylindrical** projections are created by first wrapping a plane into a cylinder and then projecting the grid is projected onto that cylinder. The cylinder is then unrolled into a flat map. **Conic** projections are created by first wrapping a plane into a cone onto which the projecting the grid is projected. The cone is then unrolled into a flat map. **Mathematical** projections oftentimes resemble geometric projections but cannot be developed by projective geometry. Mathematical projections sometimes are sub-classified as pseudocylindrical, pseudoconic, and pseudoazimuthal.

Area, shape, distance, and direction are the properties of a projection. No projection can maintain all four of these properties simultaneously. There are map projections that do a good job at minimizing distortion of one of these properties. The two most commonly employed are equivalent (equal area) projections and conformal projections. **Conformal** map projections maintain the *angular relationships* of the globe the projection surface. On the globe, arcs of latitude and longitude intersect at right (90°) angles. Thus, on the map projection, graticule lines intersect at right angles creating a rectangular map and the *shapes* of small areas will be maintained. **Equivalent** map projections maintain *size* relationships. *No* map projection can maintain both conformal and equivalent properties. Refer to Chapter 3 of the textbook for a detailed discussion on maintaining distance and direction as well as minimum error projections.

Projection **case** refers to the location that the projection surface comes in contact with the reference globe. In **tangent** projections, the projection surface touches the globe at one point (planar projections) or along one line (cylindrical and conic projections). In **secant** projections, the projection surface cuts through the globe, touching along two lines (cylindrical and conic projections) or one line for planar projections. **Reference lines** are the locations where the projection surface touches the globe. Distortion will be least on a map along the reference line(s).

Projection **aspect** refers to the "point of view" of the projection. A projection's **normal aspect** is the aspect that produces the simplest geometry for the graticule. For example, a graticule made up of straight lines of latitude and longitude intersecting at right angles is geometrically simpler than a graticule made up of complex curves. There are four aspects a projection may have: **Polar**, **Equatorial**, **Oblique**, and **Transverse**. A polar aspect is one where the map is viewed at the poles, equatorial is viewed at the equator, and oblique is a view over latitude between the equator and a pole. The exception is in conic projections, where the aspect corresponds to the point on the earth over which the *point of the cone* lies (i.e., if the point of the cone is over the pole with the projection surface touching in the mid-latitudes, the aspect is polar not oblique). The transverse aspect is the view 90°from the normal aspect (polar instead of equatorial and vice versa).

In this exercise, you will:

- ✓ Change the projection of a map
- ✓ Explore the various projection families
- ✓ Change the central meridian of a map projection
- ✓ Change the display units of your map
- ✓ Resize your data frame in a layout to specific dimensions
- ✓ Insert a neatline

Projections in ArcMap

- Start ArcMap (**Start All Programs >ArcGIS >ArcMap**); if there is an icon on the computer desktop, you can start ArcMap by double-clicking it. You will be shown a window asking whether you want to open a new empty map, a template, or an existing map.

- Make sure the **An existing map:** radio button is selected and click OK. If you did not see this window, click **File** >**Open**.

- Browse to where you saved the **projections.mxd** project file and open it. You will see a map of the world with the graticule displayed in the Table of Contents. You also will see an additional layer, Circles, in the Table of Contents that is not turned currently displayed.

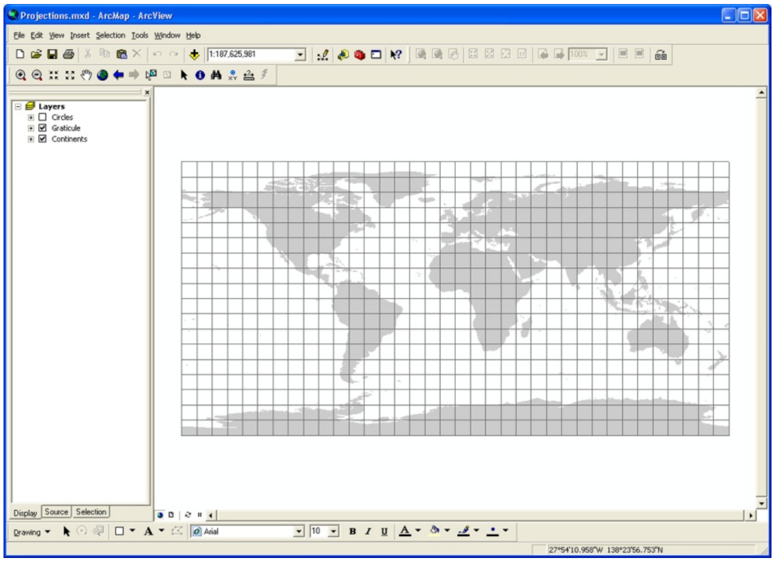

Figure 1. The map of the world with the graticule.

The portrayal of the world seen in Figure 1 is the default display for all new projects in ArcMap. Even without experience in working with projections, it should be obvious that this display is not appropriate for all mapping applications. Note, in particular, the distortion of land areas in the high latitudes.

- **Move the cursor around the data view**. As you do this, look in the status bar at the bottom of the screen. If you cannot see the status bar, turn it on by selecting **View >Status Bar**). **Notice how the numbers change as the cursor moves**. These numbers indicate the location of the cursor. Depending on the properties of your map projection, the units displayed may be DMS (degrees, minutes, seconds), decimal degrees, or coordinates using a linear measurement (like meters).

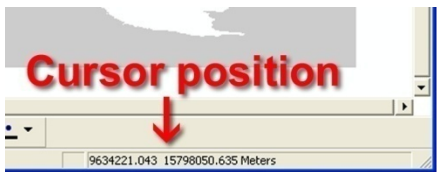

Figure 2. The values will change as your cursor moves.

You will explore some of the projections available to you in ArcMap and observe distortion that occurs in the various projections. There are two methods that cartographers use to determine distortion of map projections. The first method is to overlay geometric symbols, usually circles, on the map at multiple locations. When the projection changes, the distortion of the symbols noticeable. The second method is to employ *Tissot's indicatrix*. Tissot's indicatrix uses a small circle with two perpendicular radii placed on a map. As with the first method, the circle may change shape as the map is reprojected. The difference between the two methods lies in the fact that Tissot's indicatrix employs mathematics to quantitatively describe the distortion.

You will use the first method in this exercise to observe map distortion.

- Turn on the **Circles** layer by clicking its check box in the Table of Contents. You will see 23 circles distributed throughout the graticule. Along individual lines of latitude or longitude, the circles are spaced 80° apart.

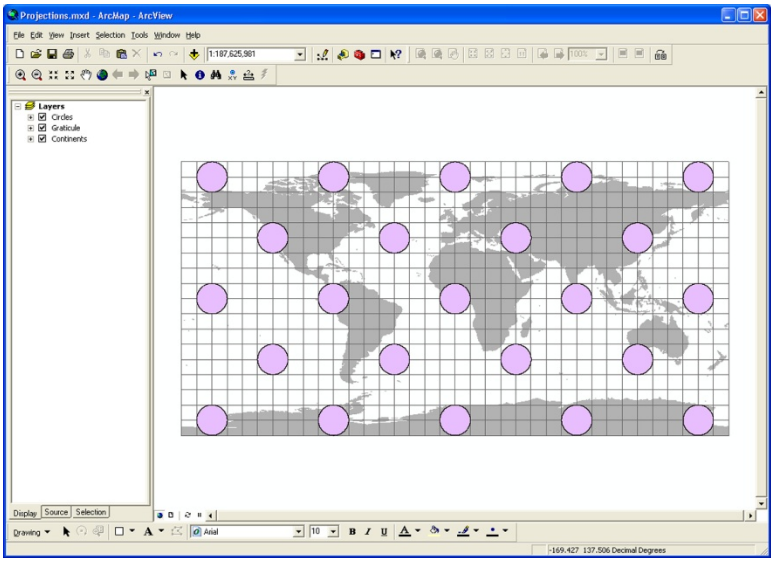

Figure 3. Your map with 23 identical circles.

To get a sense of the types of map projections available to you, let's experiment with selecting different projections and see what happens with our map.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.

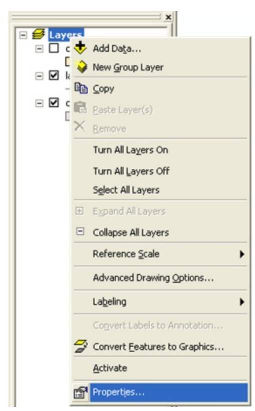

Figure 4. Right-click on the data frame, not a layer.

- Click the **Coordinate System** tab.

A data frame may use either a geographic coordinate system or a projected coordinate system. A geographic coordinate system (GCS) is a geometric model, commonly an ellipsoid, are used as a reference surface for determining location on the Earth's surface. A projected coordinate system, or projection, is the specific transformation of the 3-D earth to the 2-D flat surface. All projections use a GCS.

Note that the data frame currently employs the GCS_WGS_1984 coordinate system using the WGS_1984 datum. Refer to Chapter 2 for more information regarding ellipsoids and datums.

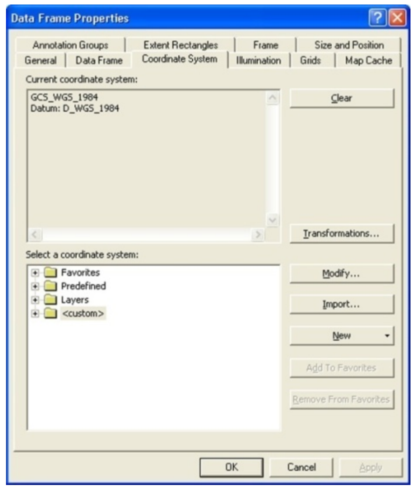

Figure 5. The coordinate system for the data frame.

You will first select a projection from the **azimuthal** family. Cartographers use azimuthal projections primarily to map the polar regions.

- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >Polar >North Pole Azimuthal Equidistant**.

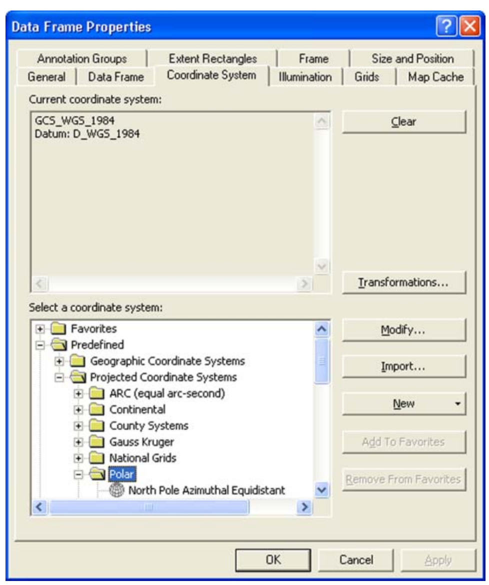

Figure 6. Selecting the North Pole Azimuthal Equidistant projection.

- Click **OK** to register the change and close the Properties window.

- You may need to adjust the view of the map to see the full extent of the mapped area. To do this click the **Full Extent** button on the Tools toolbar.

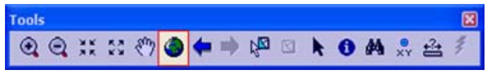

Figure 7. The Full Extent tool.

- Make a note of the appearance of the graticule. Are the latitude and longitude lines straight lines intersecting at right angles? Are the geometric symbols still circles? How are they distorted? Is the distortion the same in all parts of the map?

The exercise questions at the end of this exercise include those asking you describe the graticule and circle transformations of each of the projections you will employ. If your instructor requires you to submit the answers to the exercise questions, it is more convenient to answer them as you progress through this exercise rather than once you have completed it.

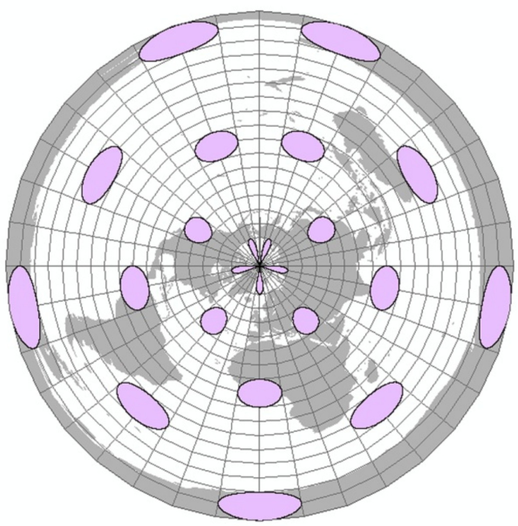

Figure 8. The North Pole Azimuthal Equidistant projection.

It should be apparent why azimuthal projections are not suitable for mapping the entire world. Note the distortion in the southern hemisphere, particularly that of Antarctica.

Next you will select a projection from the **conic** family. Cartographers use conic projections primarily to map the areas in the mid-latitudes, especially those with wide east-west dimensions.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.

- If it is not already selected, click the **Coordinate System** tab.

- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >Continental >Asia >Asia North Albers Equal Area Conic**.

- Click **OK** to register the change and close the Properties window.

- You may need to adjust the view of the map to see the full extent of the mapped area.

Make a note of the appearance of the graticule and circles.

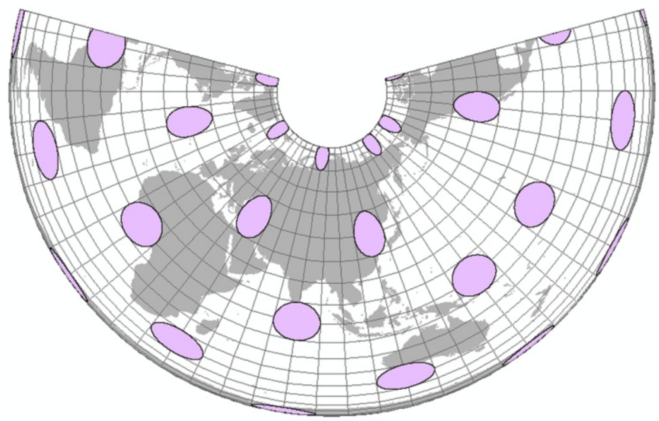

Figure 9. The Asia North Albers Equal Area Conic projection.

As with azimuthal projections, conic projections are not well suited for mapping the entire world. Use conic projections for continental areas or larger scales (e.g., countries or country subdivisions).

Next you will select a projection from the **cylindrical** family. Cartographers use cylindrical projections primarily to map the polar regions.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.

- If it is not already selected, click the **Coordinate System** tab.

- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Miller Cylindrical**.

- Click **OK** to register the change and close the Properties window.

- You may need to adjust the view of the map to see the full extent of the mapped area.

Make a note of the appearance of the graticule and circles.

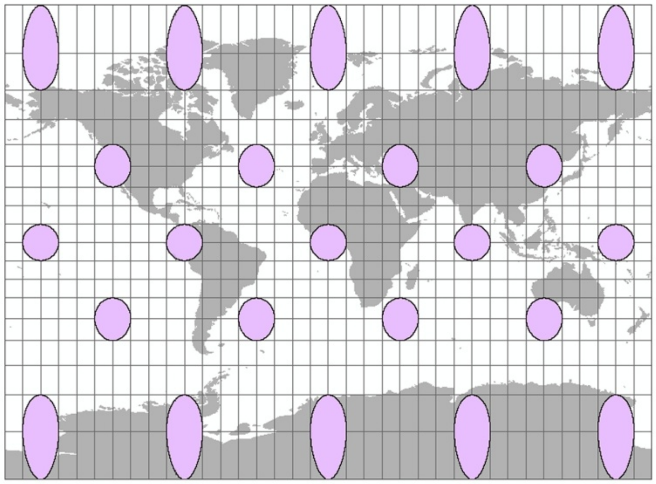

Figure 10. The Miller cylindrical projection.

Every map projection has a default *central meridian*. By default, the world map projections use the Prime Meridian (0°). When making your own maps, use the default central meridian **only** if it is appropriate to your map. In most cases, especially when mapping at large scales, you will need to adjust your central meridian.

Let's change the central meridian of the Millar Projection so that it passes through Asia.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- Click the **Modify** button. The Projected Coordinate System Properties window opens.
- Change the **Central Meridian** value to **90** and click **OK** to register the change and return to the Layer Properties window.
- Click **OK** to close the Properties window and return to the map.

Note the repositioning of the map around the new central meridian.

In the Coordinate System window you can customize the projection so that it is centered on a particular area, simply by redefining the central meridian, standard parallel(s), reference latitude, or false eastings and northings. The choice of parameters varies depends on which projection is being used. Let's briefly define these terms.

- **Central meridian –** the longitude on which a map is centered (x-origin). Do not confuse the central meridian with the Prime Meridian, which is 0° longitude. Many world maps use the Prime Meridian as the central meridian, but the central meridian may be *any* meridian.
- **Latitude of origin –** the latitude on which a map is centered (y-origin).
- **Standard parallel(s) –** for conic projections, the parallel(s) along which the cone touches the earth.
- **False easting –** in ArcMap, the x-coordinate value for the x-origin. For example, if the central meridian for your projected map is -96.00, and the false easting is set to 0.00, then all locations along that meridian are assigned a value of 0.00. All locations to the west of the central meridian (x-origin) are assigned a negative value, and all locations to the east of the central meridian are assigned a positive value, as in a typical Cartesian plane.
- **False northing –** in ArcMap, the y-coordinate value for the y-origin. For example, if the reference latitude for a conic projection is 37.00, then all locations along that parallel are assigned a value of 0.00. All locations to the south of the reference latitude (y-origin) are assigned a negative value, and all locations to the north of the reference latitude are assigned a positive value, as in a typical Cartesian plane.

When specifying longitude and/or latitude values in the various properties widow, you do so in **decimal degrees**. If you have a location where the coordinates are given in degrees, minutes, and seconds (DMS), you will need to convert to decimal degrees. When converting, remember that there are 60 seconds in a minute and 60 minutes in a degree. Also note that positions *west of the Prime Meridian* and *south of the Equator* are assigned **negative** values. For example, Denver, Colorado's DMS coordinates of 39° 45' N, 104° 52' W would convert to 39.27°, -104.87°.

- Move your cursor around the map and note the position of the cursor in the status bar at the bottom of the window.

As you can see, the values given are in meters, which is not particularly useful for simple exploration of map coordinates. You will next change your display units to DMS.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- This time, click the **General** tab.
- In the Units area change the **Display** to **Decimal Degrees**.

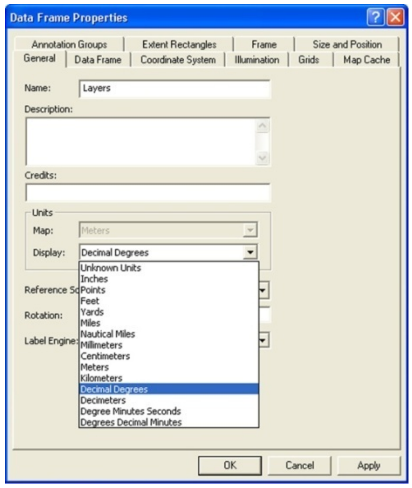

Figure 11. Changing the map display units to decimal degrees.

- Click **OK** to close the Properties window and return to the map.

Now notice the change in the display of the coordinates in the status bar as you move your mouse around the map. Be sure to move the cursor west of the Prime Meridian and south of the Equator to see the negative longitude and latitude values in those locations.

Cylindrical projections are much better for mapping the entire world than azimuthal or conic projections. However, most cartographers dissuade using cylindrical projections for world mapping because of the substantial distortion in the high latitudes. For world mapping, cartographers prefer **mathematical** projections.

You will next view your map using two different mathematical projections. The first is the Robinson projection. The Robinson projection is a compromise projection that is commonly used for world mapping.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.

- If it is not already selected, click the **Coordinate System** tab.

- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Robinson**.

- Click **OK** to register the change and close the Properties window.

- You may need to adjust the view of the map to see the full extent of the mapped area.

Make a note of the appearance of the graticule and circles.

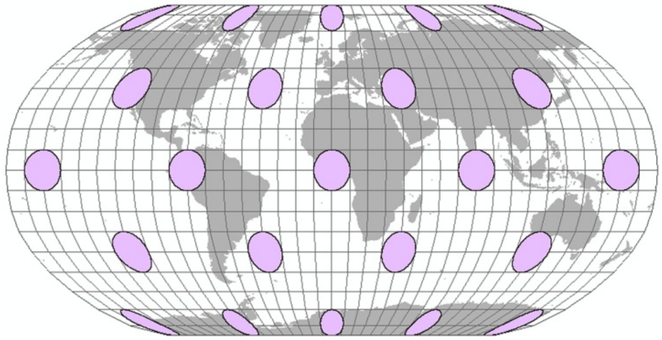

Figure 12. The Robinson projection.

It is important to note that not all the projections listed in the World subsection of the projected coordinate systems are ideal for maps of the world. The Bonne projection is an equal area conical projection is noteworthy for its distinct heart (cordiform) shape.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Bonne**.
- Click **OK** to register the change and close the Properties window.
- You may need to adjust the view of the map to see the full extent of the mapped area.

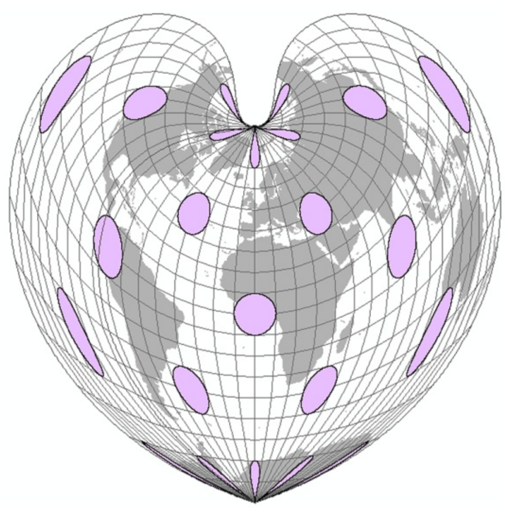

Figure 13. The Bonne projection.

Cartographers use the Bonne projection for continental areas and countries in the mid-latitudes.

Creating a Map to Turn In

The final projection you will use in this exercise is the Orthographic projection. Referred to as the Vertical Perspective projection in ArcMap, this projection is used primarily to view the Earth as if from space.

- Before changing the projection, **turn off** the circles layer.
- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Vertical Perspective**.
- Click **OK** to register the change and close the Properties window.

It may take slightly longer to draw the map using this projection than the other projections. If so, be patient, it will draw completely.

- The map may appear relatively small in the data view. If so, click the **Full Extent** button to enlarge it.

You will now see the world as if you were in a position in space above the intersection of the Prime Meridian and the Equator.

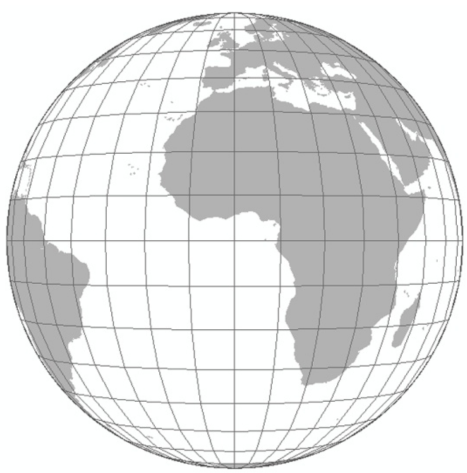

Figure 14. The Vertical Perspective (Orthographic) projection.

Next you will change the aspect of the projection so that you are viewing the Earth from above *your current position*. Use an atlas, online site (such as www.lat-long.com for U.S. cities), or program like Google Earth (if you have it installed) to determine your coordinates. Your instructor may also provide coordinates for you to use.

- Return to the **Coordinate System** tab of the **Data Frame Properties** window.
- Click the **Modify** button. The Projected Coordinate System Properties window will open.
- Change the values of both **Longitude Of Center** and **Latitude Of Center** to **your coordinates**. Remember that you must use **decimal degrees** and also use **negative numbers** for longitudes west of the Prime Meridian and latitudes south of the equator. Do not change the Height or Linear Unit values.

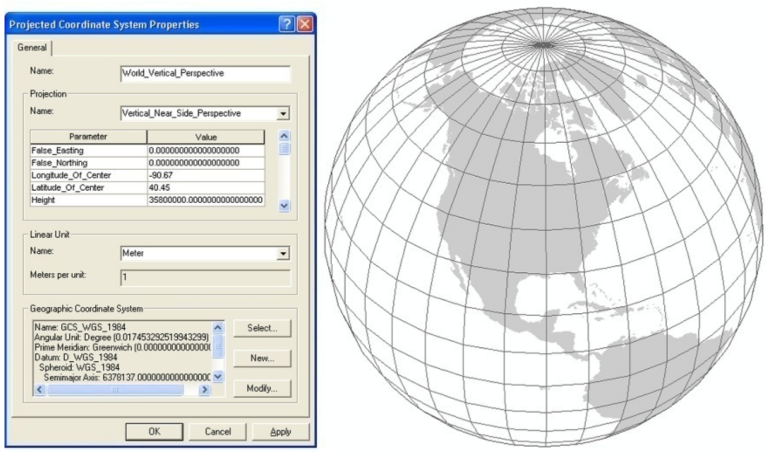

Figure 15. The Orthographic projection reoriented over Macomb, Illinois.

- Click OK to register the change

Creating the Layout

- Switch to the **Layout View** (**View** >**Layout View**).
- Using the **Page and Print Setup** menu item (right-click outside the page in the layout view to get the context menu where this is located), **change the Orientation** to **Landscape**. Also make sure the **Use Printer Paper Settings** and **Show Printer Margins on Layout** boxes are checked.

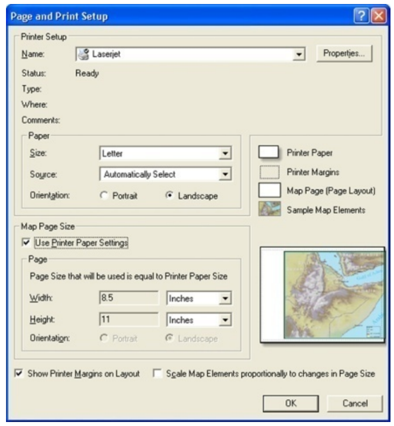

Figure 16. Page and Print Setup.

- Click **OK** to register your changes and close the window.

When you changed the orientation of the page from portrait to landscape, your data frame did not resize. You will need to resize the data frame to fit in the layout. Resizing is accomplished in one of two ways: clicking and dragging one of the sizing handles (boxes that appear along the edge of the data frame when the data frame is selected) or adjusting the size of the frame in the Data Frame Properties window. You will do the latter.

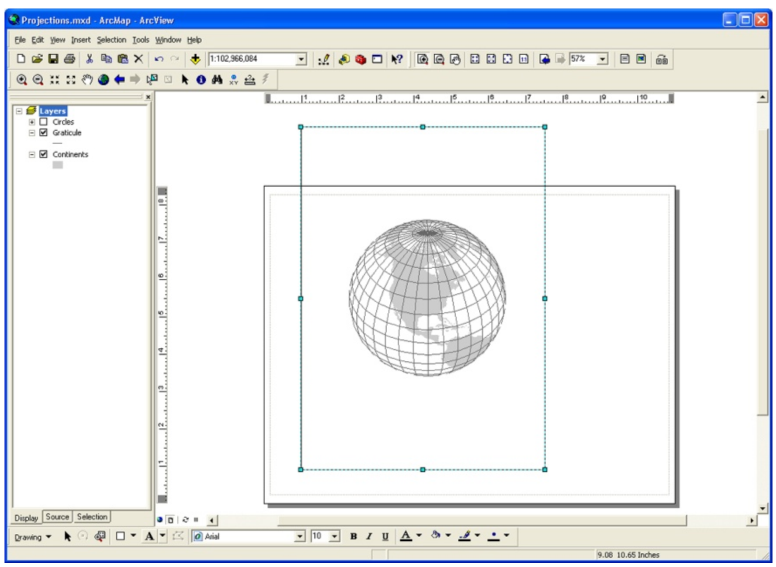

Figure 17. Your data frame no longer fits the layout following the switch to landscape orientation.

- **Right-click** the **data frame** (mapped area) and select **Properties**.
- Click the **Size and Position** tab.
- Change **both** the **width** and **height** to **7.5 in**.

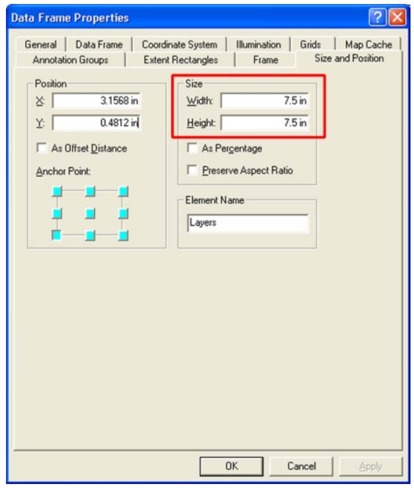

Figure 18. Setting the dimensions of the data frame.

- Before closing the Data Frame Properties window, click the **Frame** tab.

- Change the Border to **<None>**.

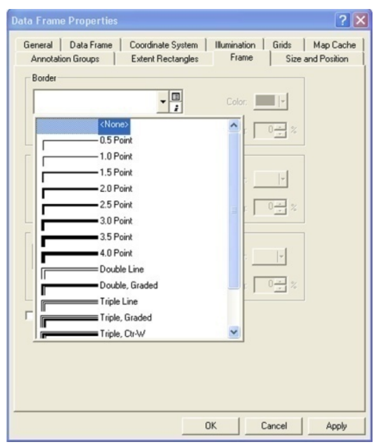

Figure 19. Click the Border box to make the change.

- Click **OK** to register your changes and close the Data Frame Properties window.

By resizing the data frame, the scale of the map may have changed—it is common for you to be at a smaller scale than you were in the data view following the resizing.

- If necessary, zoom to fill the data frame with the mapped area. Use the *Full Extent* button (it looks like a globe) to do so.

- Click OK to register your changes and close the Properties window.

- Insert a **neatline** (**Insert >Neatline**). Make it **2 points** thick and place it inside the print margins with a **5 point** gap.

- Next, reposition the data frame so it is near the right edge of the layout, inside the neatline.

- Add the **map title** (**Insert >Title**). Make your map title **Orthographic Projection of the World**.

- Reposition the title so it is in the space to the left of the mapped area.

The current size of the text used in the title should be a little bigger but making the title bigger will likely cause overlap with the map. The solution to the dilemma of how to make the title bigger but not overlap the map is to use multiple lines for the title.

- To change your text to multiple lines, **double-click** the **title**. The Text Properties window opens.

- Place your cursor **between** Orthographic and Projection and press the **Enter** key on your keyboard. Make sure you delete the space that was between the two words.

- Repeat the procedure to put "of the World" on a third line.

- Keep the alignment as center-aligned.

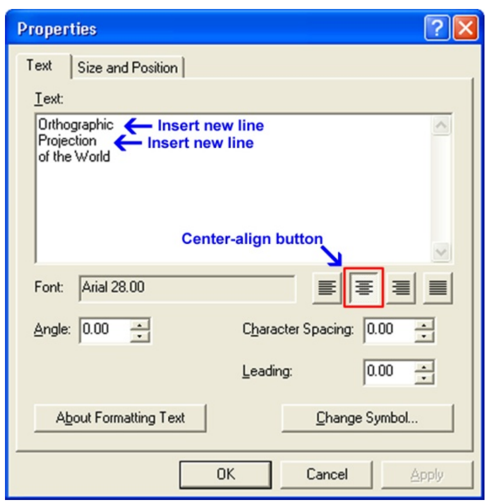

Figure 20. The title on multiple lines.

- Using the Drawing toolbar (placed by default at the bottom of the ArcMap window), make the title text **bold** and increase its **size** (try between 28 and 34 points).

- Reposition the title if necessary to fit in the available space.

- Next, add a new text element indicating the orientation of the map (substitute your information for the items in brackets):

Map oriented on [your location]
[your latitude and longitude coordinates]

- Position this text below the title.

- In the lower left-hand corner of the page, add the cartographer information (two lines, left-aligned):

  Your name
  Today's date

To print a hard-copy of the map:

- Click on the **print button** or select **File** >**Print** (you may also print preview using **File >Print Preview**)

To create a PDF document (for digital submissions):

- Export the map by selecting **File** >**Export Map…**

- Change the **Save as type:** to **PDF (*.pdf)**.

- The Resolution should be **300** dpi and the **Output Image Quality** should be **best**. Keep these settings unless directed otherwise.

Exercise Questions

1. What are the steps to applying a projection (projected coordinate system) to a data frame?

2. Which projection family is most suited to map (a) the world, (b) the mid-latitudes, and (c) the polar regions?

3. What is a *central meridian* and how do you change it in ArcMap?

4. What is the *latitude of origin* and how do you change it in ArcMap?

5. How do you specify your display units as Degrees, Minutes & Seconds?

6. What is a generating globe?

7. What are *conformal* and *equivalent* projections?

8. What is a projection's *aspect*?

9. Describe the *graticule* of the North Pole Azimuthal Equidistant, Asia North Albers Equal Area Conic, Miller Cylindrical, and Robinson projections.

10. Describe the *transformation of the circles* when you applied the each of the projections. Are there any true circles in this projection? If so, which ones?