Lab 9: TOPOGRAPHIC MAPS

Topographic maps are rich sources of geographic information. Geologic maps are commonly constructed upon topographic base maps, and much geological mapping, sampling and other field work relies on topographic maps for accurately locating features in the field. In additional to displaying topographic information, topographic maps commonly show other important data, including grids for at least two and sometimes three different coordinate systems (Lat. & Lon. UTM, PLS systems), roads and trails, vegetative cover, property and political boundaries, and many other landmarks of permanence (cemeteries, churches, schools, etc.). This information, when coupled with elevation contours, provides an easy, rapid and precise means of determining positions and distances. A thorough appreciation of all of the aspects of topographic maps is particularly important for field geologists because these maps are among the most important resources for fieldwork.

I. Production of Topographic maps in the US

Topographic maps of the US are produced by the US Geological Survey (USGS), which makes maps available to the public in quadrangle and map series at a number of different scales (see below). Since about the late 1930s, the USGS has relied on aerial photographs and the science of photogrammetry to produce accurate maps, which in early times were constructed by direct field surveys. Lines of latitude and longitude border all USGS topographic maps.

<u>Geodetic Datums</u>

A map is a projection of a portion of the ellipsoidal earth onto a plane. Such projections require: 1) a model of the size and shape of the earth, 2) a technique or algorithm for transferring the *graticule* (lines of latitude and longitude) onto a plane. For map-making purposes, a model of the shape of the earth is called a *geodetic datum*. Hundreds of different datums are in use around the world, all yielding slightly different solutions for the spacing of the graticule on maps after projection. On USGS topographic maps two datums are in common use, the North American Datum, 1927 (NAD27) and the North American Datum, 1983 (NAD83). A third, the World Geodetic System Datum, 1984 (WGS84) has gained international acceptance and is the datum of choice for all new maps and map series. WGS84 is the default datum for many survey applications, including GPS. NAD83 and WGS84 are identical and yield common projections of the graticule for the conterminous US. The same is not true of NAD27, which yields slightly different spacings and positions for meridians and parallels. The vast majority of USGS paper map products, which were produced prior to 1983, are still today referenced to NAD27. On maps produced or revised after about 1985, graticule intersections for both NAD83 and NAD27 are often shown, commonly in different colors at the corners of the map. In the Austin area, the two differ in position by about 20 meters in latitude and 30 meters in longitude. The map datum is always stated somewhere in the map collar (white region surrounding the map), commonly in the lower left corner with other information.

Map Projections

The surface of the earth cannot be laid flat without distorting either distances (=area) or angles (or both). The choice of which to distort and the extent to which the distortion is minimized depends on intended use of the map. Maps for navigation are most useful if bearings can be represented as straight lines (rhumb lines). Likewise, maps of property ownership are most useful if areas of the same size have the same dimensions everywhere on the map. The type of map projection determines the type and amount of distortion. Map projections that are "***conformal***" (like all USGS topographic maps) distort distance (and area) but preserve angular relationships. Small areas remain relatively undistorted but conformal maps are unsuitable for large regions. **Equal area projections**, as the name implies, preserve area and distance but distort angles. **Equidistant projections** preserve neither angles nor areas, but distance relationships in certain directions are maintained.

Three common projections are:

Mercator – Can be recognized by the rectilinear grid of meridians and parallels. Formed by wrapping a cylinder (the "developable surface") about an ellipsoid so that the line of contact (the "tangoid"; line of no distortion) is the equator (Fig. 1). Distortion increases with distance from the tangoid.

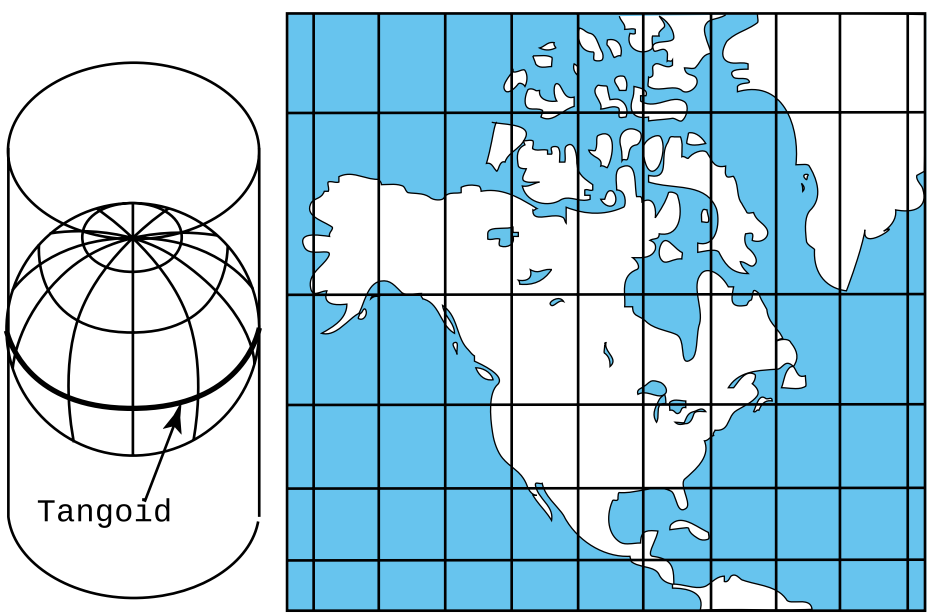


Figure 1. The Mercator projection.

Transverse Mercator - Same as above except cylinder intersects ellipsoid along a meridian, i.e. the axis of the cylinder is horizontal rather than vertical (Fig. 2). The UTM grid coordinate system (described below) is based on this projection. Like the Mercator, the Transverse Mercator projection gives perpendicular lines of latitude and longitude but, except for the meridian of intersection (tangoid), all are curved.

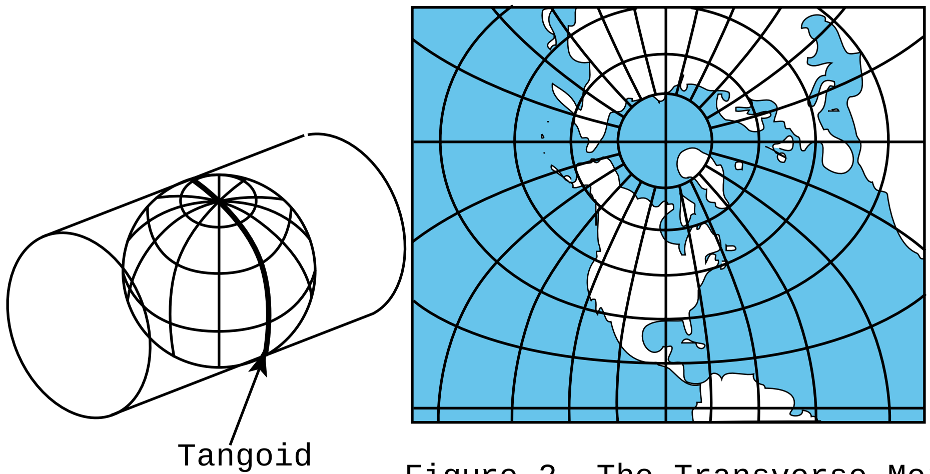


Figure 2. The Transverse Mercator projection.

Lambert Conformal Conic: Ellipsoid is projected onto a cone whose axis coincides with the polar axis (Fig. 3). The line (or lines if the cone penetrates the ellipsoid) of intersection is usually a line of latitude. Lines of longitude converge toward the poles and lines of latitude are concentric arcs. Most USGS paper maps are Lambert Conformal Conic projections with borders that are lines of latitude and longitude. As such, they are not absolutely rectangular but have slightly arcuate upper and lower edges and converging sides.

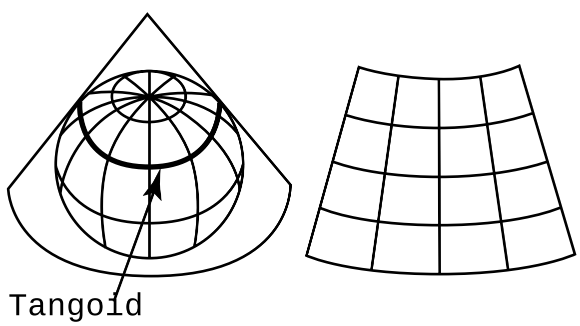


Figure 3. Lambert Conical projection

Digital Topographic Maps

The USGS now publishes many of their products, including many of the topographic map series, in digital form. High-resolution (250 dpi), scanned versions of most paper topographic maps are called *Digital Raster Graphs* (DRGs). These are best thought of as pictures of topographic maps and are discussed in greater detail in Lab 12. All USGS DRGs have been reprojected to the UTM to standardize all maps. This creates a conflict between the digital version and the original scanned mapped, which are typically Lambert Conformal Conical projections that contain collar information for the original projection. GIS and other software can account for these differences, as discussed in Lab 12.

Truly digital topography (i.e. data files containing horizontal and vertical coordinates for a grid of points encompassed by a map) is rapidly becoming available for most map series. These products, also being produced by the USGS, are referred to as Digital Elevation Models (DEMs) and can be used, with appropriate software, to construct custom contour maps and 3-D renderings of topography.

Finally, roads, streams, political boundaries and other linear features found on standard topographic maps are also available in digital version as Digital Line Graphs (DLGs).

Remarkably, most of these products are available free via the Internet (see the class web sites for links). They can also be purchase through commercial vendors or the USGS, which distributes them on CDs.

II. Map Scales

All topographic maps are scaled equivalents of the earth's surface. Map scales are stated as ratios of distance on the map to the distance on the ground, e.g. a scale of **1:24,000** is equivalent to stating that 1 unit on the map is equal to 24,000 units on the ground. This is the so-called "R.F." (Representative fraction) scale and is, of course, dimensionless. It is good practice to be able to estimate distances quickly from R.F. scales. One might ask, for example, what is the ground distanced represent by the width of a pencil line (i.e. 0.5 mm) on a 1:12,000 map? (Answer: 6 meters).

Map scales are also expressed graphically by bar scales, typically in both English and metric units. Bar scale increments are always convenient whole numbers, regardless of the units, resulting in scale bars of different lengths for different units.

All USGS map boundaries are parallels of latitude and meridians of longitude. USGS topographic maps are available in "series" that are denoted by scale and the area encompassed by the map, e.g. 7.5 minutes series maps cover a 7.5 minutes x 7.5 minutes area. Common series and scales are:

Series	Scale	Size	1 inch equals about:
7.5 - minute	1:24,000	7.5 x 7.5 min.	2000 feet (exact)
15 - minute	1:62,500	15 x 15 min.	1 mile
County	1:100,000	60 x 30 min.	1.6 miles
2^o sheet	1:250,000	2^o x 2^o	4 miles

III. Contour Intervals

Contours are lines connecting points of equal elevation above or below mean sea level (MSL), the vertical datum for all USGS topographic maps. A contour interval specifies the difference, in feet or meters, in elevation between two adjacent contour lines. Smaller contour intervals are useful for flat areas, larger ones for areas of great topographic relief. USGS map series typically show smaller contour intervals on larger-scale maps (i.e. 7.5 minute). Common contour intervals on such maps are 20 feet or 10 meters. At smaller scales, contour intervals are typically 40, 60, 80, 100 or 200 feet, or 20, 30 or 50 meters.

IV. North Arrows

Geographic, magnetic and "grid" north are commonly represented by a declination diagram or "north arrow" on all USGS topographic maps (Fig. 4). The diagram shows the orientation of theses three directions at the center of the map sheet. The Grid North (GN) arrow or line is parallel to a UTM meridian (see below) which, depending on the map scale, type of projection and location of the area, may or may not be parallel to a line of longitude on the map. The arrow for geographic (true) north is always surmounted with a 5-point star.

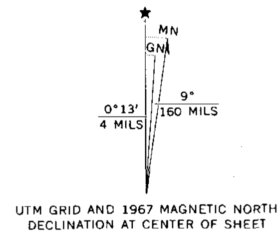


Figure 4

V. Grid Reference Systems

All USGS topographic series maps are bordered by lines of latitude and longitude and thus include, along the map collar and within the map area, graduations in degrees, minutes and seconds. A 7.5' x 7.5' map of an area within the conterminous US is more rectangular than square, meaning that increments of latitude and longitude are not of equal length. To determine the latitude and longitude of a point it is necessary to calculate scaled distance equivalents for both parameters.

<u>UTM System</u>

The second grid system on all topographic maps is the Universal Transverse Mercator (UTM) coordinate system. As discussed in class, this system is based on dividing the globe into 6^{o}-wide "zones" bounded by lines of longitude (Fig. 5). Zones are numbered consecutively, moving east from the international dateline, from 1 to 60. The zone number for the UTM grid on a map is given in the map information in the lower right corner of the map sheet.

Locations within a zone are given with reference to the equator and a "central meridian" for the zone. Labeled graduations on the map list coordinates, in meters, north or south of the equator ("Northings") and east or west ("Eastings") of the central meridian for the zone, which is arbitrarily assigned a value of 500,000 meters (the so-called False Easting) (Fig. 6). Coordinates are given in a short hand notation, with the first number(s) in superscript corresponding to the millions and/or hundreds-of- thousands of meters. For example, an Easting graduation labeled $^{4}87$ is the position of a meridian that is at 487,000 meters within the zone, or 13,000 meters west of the zone's central meridian (by assigning a central meridian a value of 500,000 m, the system avoids the use of negative numbers). A UTM graduation on the vertical edge of the map labeled $^{46}49$ marks the location of a parallel that is 4,649,000 meters north of the equator. The UTM grid on 7.5' series maps has a spacing of 1 kilometer, thus graduations not labeled represent increments that, in the shorthand notation, change only by the last digit.

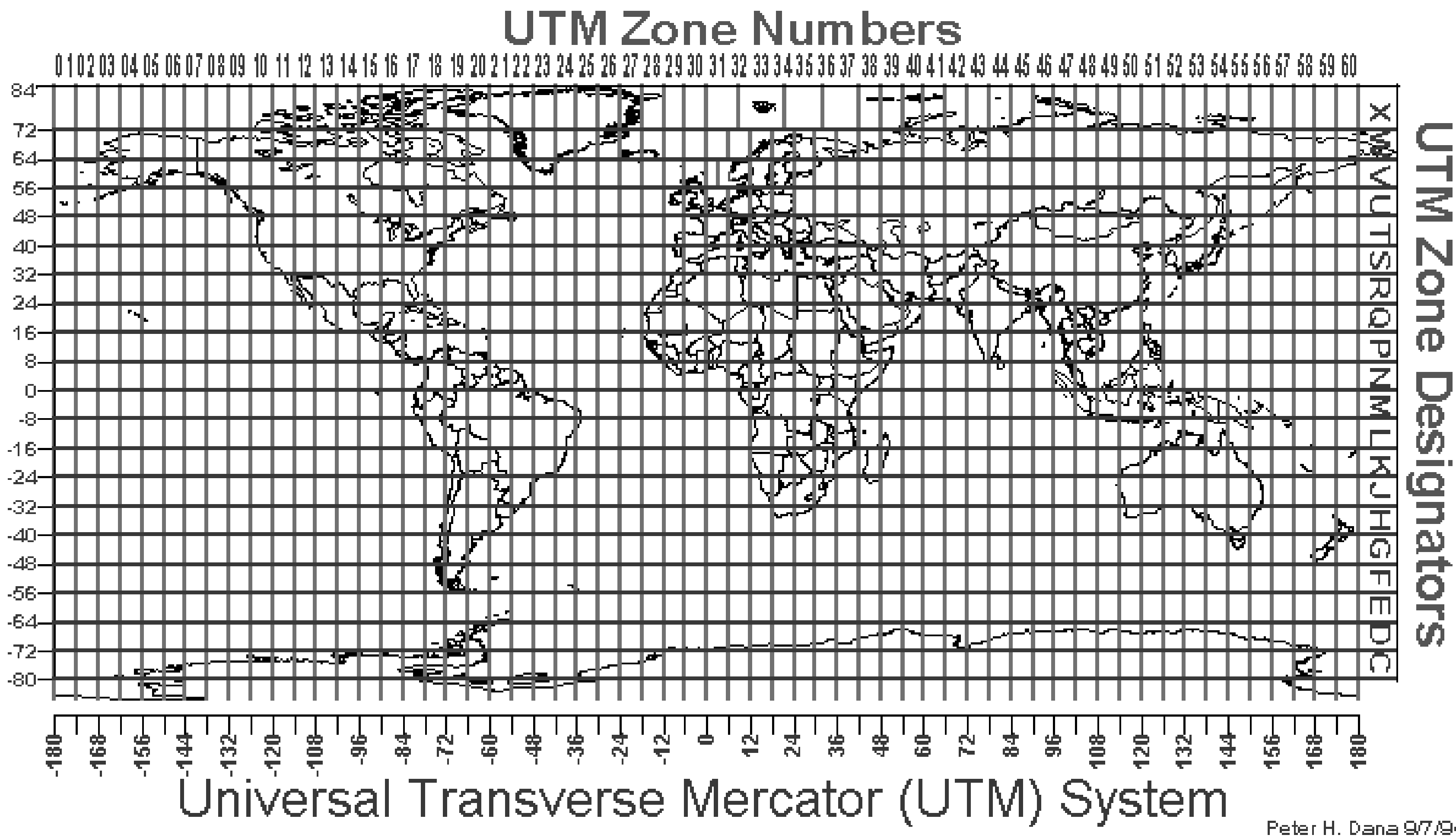


Figure 5. UTM zones of the world, on a Transverse Mercator projection (figure courtesy of Peter Dana).

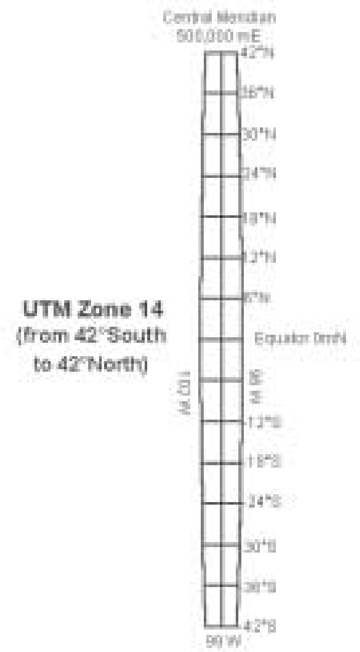


Figure 6. UTM Zone 14 (courtesy of P. Dana)

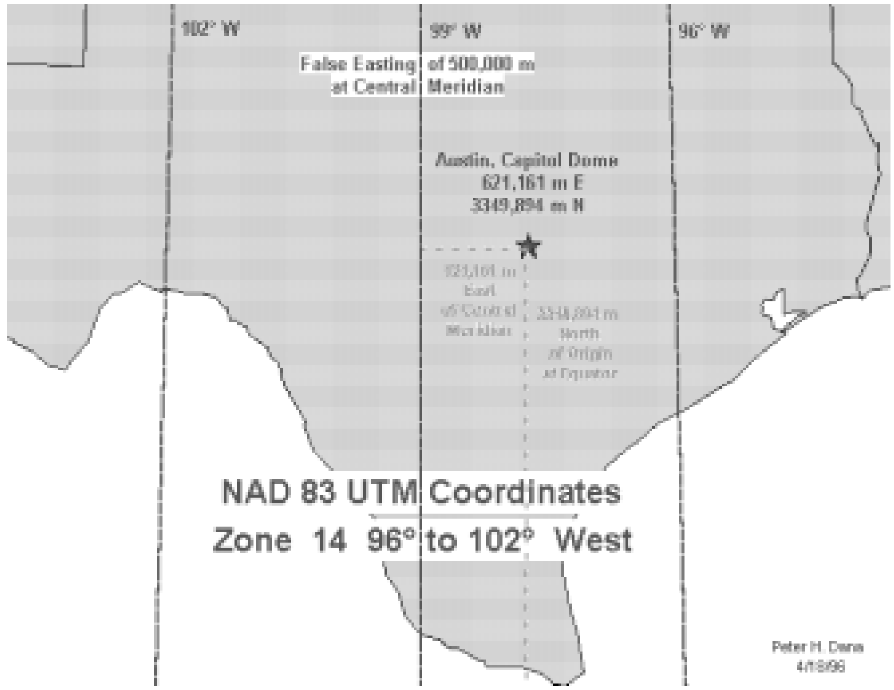


Figure 7. The location of the Texas State Capital in UTM coordinates (courtesy of P. Dana).

<u>PLS System</u>

A third coordinate system found on some topographic maps, particularly those of areas in the western US, is the Public Land Survey (PLS) grid, often referred to as the Township-Range grid or the Government grid. The grid for this system is referenced to surveyed "principle" meridians, given names for prominent geographic features (e.g. Mt. Diablo Meridian), and perpendicular parallels, called baselines. This is a regional system, with different meridians and baselines for nearly every state having a PLS grid; adjacent grids hung on different baselines and meridian do not match. The basic grid unit is the "**Township**" a 6 x 6-mile square that is label according to its location relative to the principle meridian and baseline (Fig. 8). For example, a township whose southern edge is 2 miles south of the baseline and whose eastern edge is the principle meridian is designated Township 2S, Range 1W. A 36 mi^2 township is divided in 36, mile-square "**Sections**" which are numbered consecutively, beginning in the NE corner with 1 and ending in the SE corner with 36. Sections are subdivided into ¼ sections; ¼ sections further into ¼, ¼ sections, to arrive at blocks of land that are 40 acres in area, the size of a homestead plot granted under the original Homestead Act. The location of a 40 acre tract of land could thus be stated as Township 2S, Range 1W (or simply T2S, R1W), SE ¼ of the SE ¼ of section 12 (see fig. 8). This system does not lend itself to precise location, nor is it easily converted for digital referencing. Moreover, it is a local system, not designed for anything other than platting land. Nevertheless, as the oldest available grid system in the US, it has, through the years, been adopted and adapted for a variety of uses. Familiarity with it is important, particularly for working in the mineral and/or oil and gas industry. There is no PLS grid for Texas or any of the original 13 states.

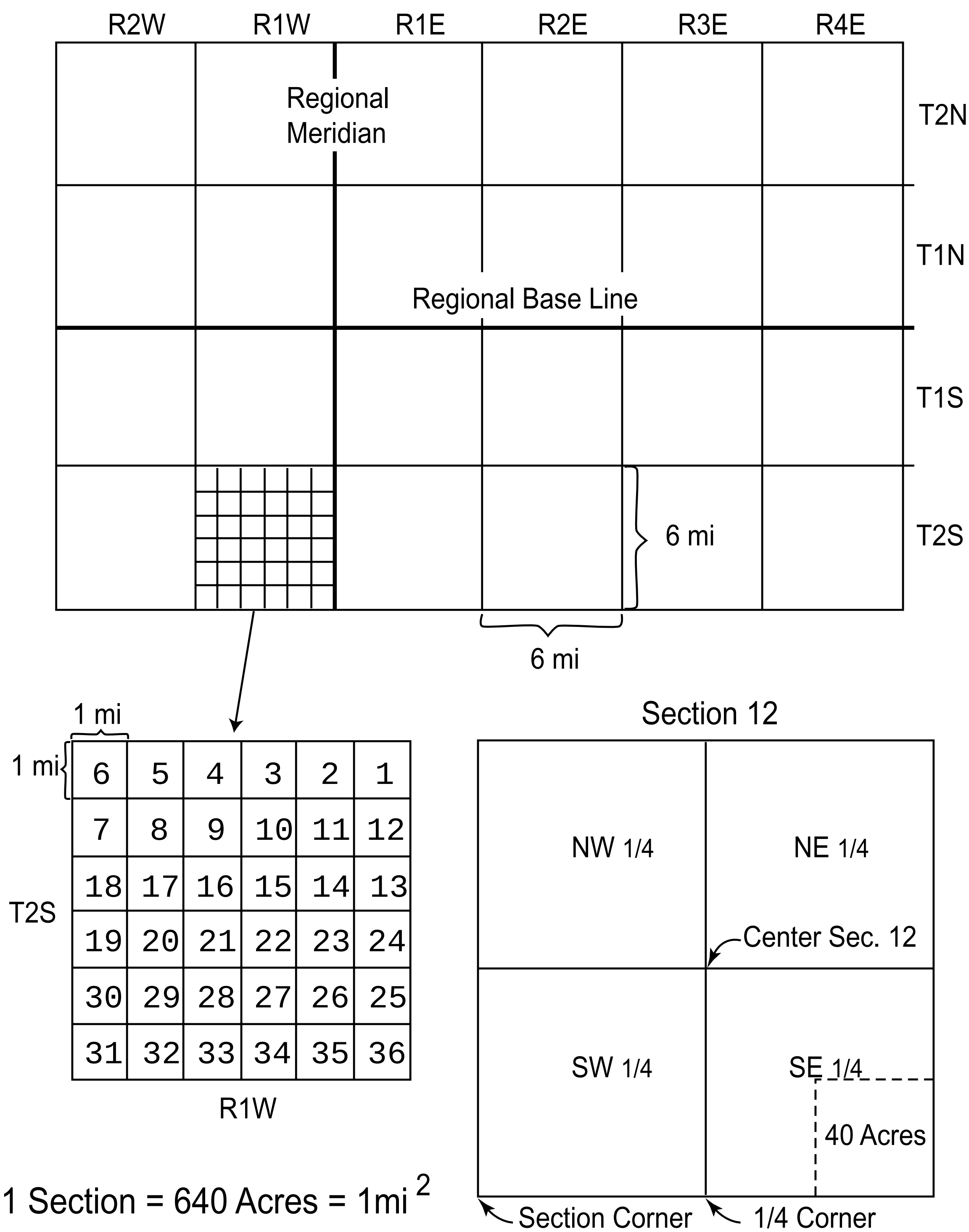


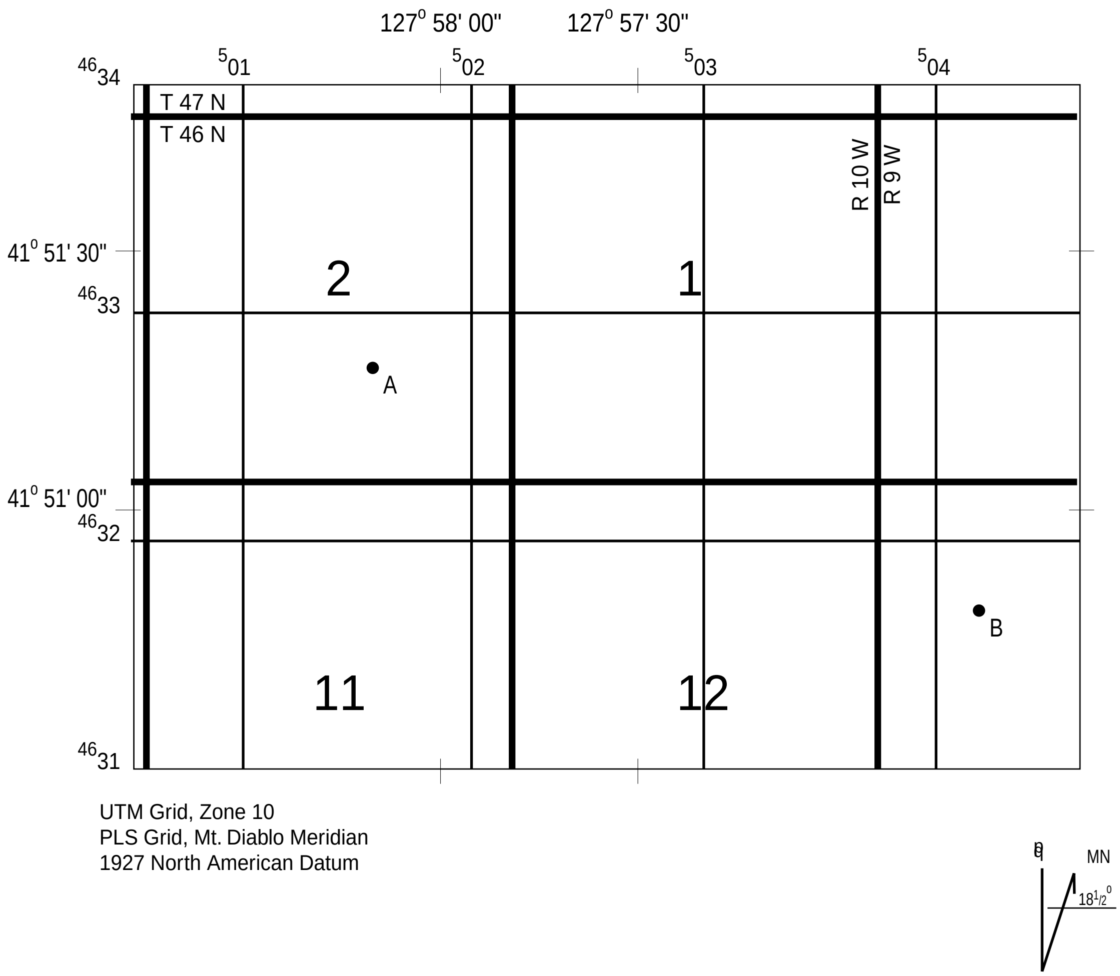
Figure 8. The PLS Grid System

VI. Topographic Profiles and Vertical Exaggeration

Topographic profiles are scaled, cross sectional views of topography. They are graphs of elevation versus distance, with all data points connected by lines. For topography to be accurately portrayed in profile, the scale of the profile's vertical axis must be equal to the scale of the horizontal axis. If the two differ, the profile is said to be vertically exaggerated.

Because topographic profiles are constructed from topographic maps, the map scale determines the scale of the axes. For example, a profile constructed from a map having a scale of 1:12,000 will have vertical and horizontal axes of 1 inch per 1000 feet. The same profile, when vertically exaggerated by a factor of two, would be a graph with a vertical axis having a scale of 1 inch per 500 feet and a horizontal axis of 1 inch per 1000 feet. Vertically exaggerated topographic profiles are commonly more jagged in appearance, showing exaggerated slopes and magnified elevation differences. In regions of subdued topography or at small map scales, vertical exaggeration provides a means of displaying small elevation differences that might otherwise not be apparent.

Exercises:



1) From the portion of the grids shown above, answer these questions:

   a) What are the locations of points A & B in degrees, minutes and seconds of Latitude and Longitude?
      A- B-
      In decimal degrees?
      A- B-

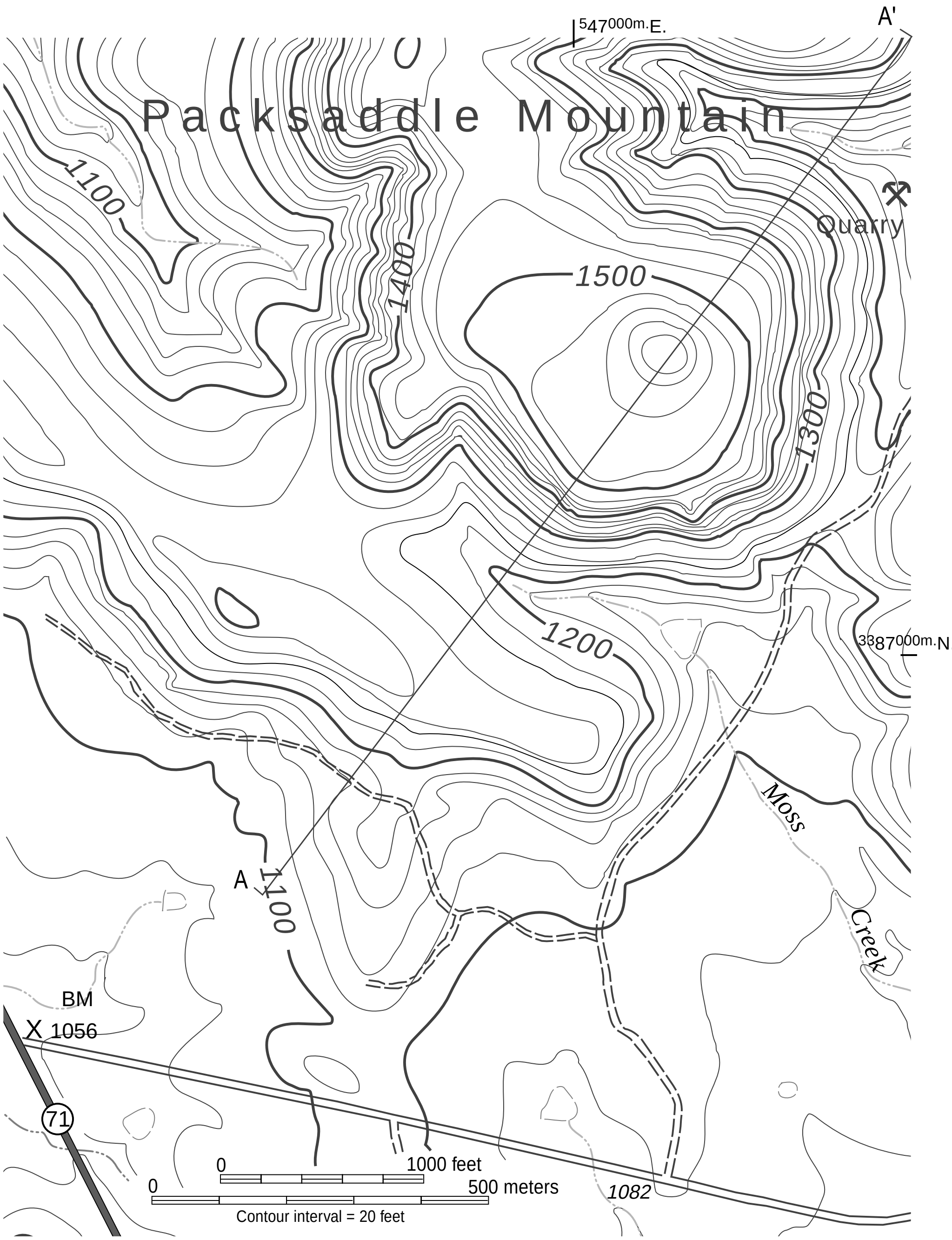
   b) What are the locations of the points in UTM coordinates?
      A- B-

   c) Where is the central meridian for UTM zone 10 in relation to this map? How far away is it?

   d) What are the locations of the points in PLS coordinates?
      A- B-

e) What is the R.F. scale of the map?

f) At this scale, if your measurements are precise to within 0.5 mm, how many meters of uncertainty should I allow in grading your UTM coordinates?



2. Answer the following questions for the map above.

a. What is the elevation of the highest point on the map?

b. What is the RF Scale of this map?

c. What is the distance along the line of profile A-A'?

d. The area lies within UTM zone 14. How far away is the area from the central meridian of zone 14? Is the central meridian East or West of this area?

e. Describe the topography one would walk over when traversing the line of profile; e.g. "Starting at A, I walk down a gentle slope and cross highway 71, then walk up a gentle slope and cross the WNW-ESE trending minor road and walk along slope until I begin to climb upslope at elevation 1080 feet. Etc. Etc."

f. Construct a topographic profile along the line A-A'. Show 1000 feet of elevation on the vertical axis, and use the map scale for vertical axis distances (do not vertically exaggerate the profile).

g. Make a second profile of line A-A' with 2 times vertical exaggeration.

Make sure both profiles include the following:

- A title, your name, and the date
- Labels for both ends of the profile (A, A') and the directions they represent (SW, NE)
- A vertical axis labeled every 200 feet of elevation.

10 SQUARES PER INCH

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