LECTURE 2: LOCATING YOURSELF ON THE EARTH: GEOREFERENCING AND COORDINATE SYSTEMS

A. Introduction

Before we discuss GIS in detail we need to describe how one determines locations on the planet. There are many methods that can be used to determine positions on the surface of the earth; the process is referred to as **georeferencing**. A common method for finding a location includes the use of landmarks and features on the earth's surface (discontinuous georeferencing), which may not always provide the sufficient detail needed to confidently locate one's position.

The method that is universally accepted involves using latitude and longitude (geographic, continuous georeferencing), which can provide a highly precise means for locating any place on the planet. Most formalized methods for determining location can utilize involve using a grid system that is superimposed on the earth's surface.

There are two approaches that can be used to determine coordinates on the earth's surface, which include: **geographic coordinate systems** and **plane coordinate systems**.

Most casual users of maps and Global Positioning System (GPS) technology know about the geographic coordinate system used to locate entities on the earth. Geographic coordinates are based on latitude and longitude, which are given as an angular measurement in degrees. At this point a basic review of latitude and longitude is in order.

B. Geographic Coordinate System

Latitude defines location on the planet in terms of north or south (Figure 1a). Lines of latitude are also called parallels and define a full circle on the surface of the earth. Zero degrees latitude is defined as the **equator**, the boundary between the northern and southern hemispheres (Figure 1a). All points north of the equator are within the northern hemisphere and will always have North latitudes. All points south of the equator are within the southern hemisphere and will always have South latitudes.

The maximum number of degrees of latitude that can be present on the earth's surface is 90^o. The North Pole has a latitude of 90^o N; the South Pole is 90^o S. Additionally, parallels of latitude are commonly labeled on world maps or globes normally in 15 or 30^o intervals (Figure 1b).

Suppose you are located at a latitude of 30° N. Note that many places on the planet are also located at approximately 30° N such as Austin, TX, northern Florida, or northern Africa (Figure 2).

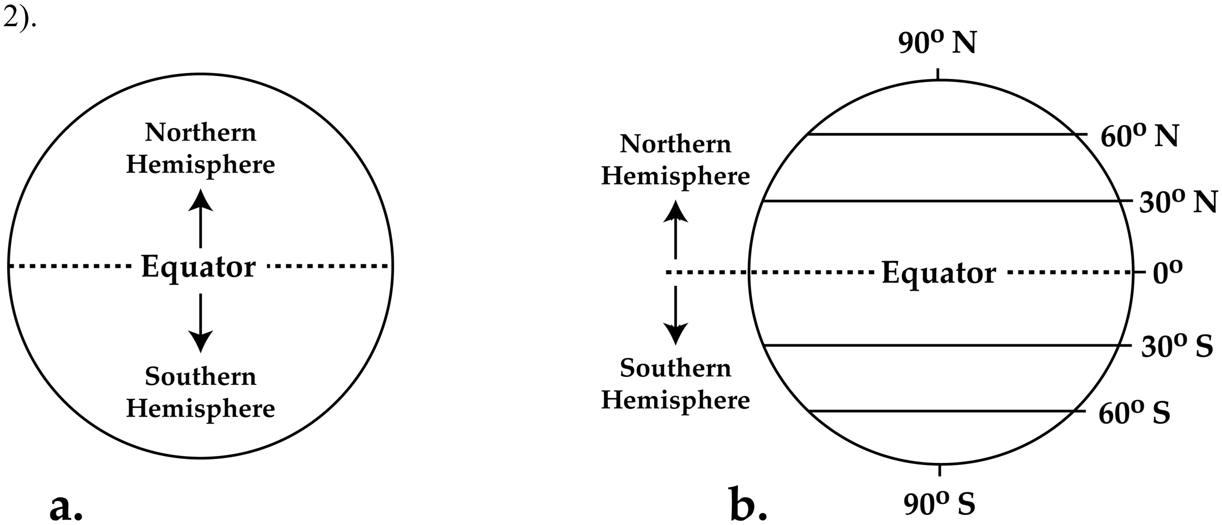

Figure 1. a) Schematic of the earth with the northern and southern hemispheres labeled.
b) The earth with lines of latitude labeled at every 30 degrees.

Longitude, the second part of this locating system, defines a position on the planet in terms of east or west. Unlike parallels of latitude, which are defined by great circles, lines of longitude (or meridians, as they are also called) form half circles which go from the north to the south pole and do not encircle the whole planet (Figure 3).

Unlike the equator, which is defined as a circle exactly halfway between the north and south pole, the zero degree meridian of longitude (the **prime meridian**) was arbitrarily defined. The prime meridian is a line drawn from the north to the south pole and is drawn through the city of Greenwich, England; because the British were the first to formalize longitude as a measure of east-west position (Figure 4).

Therefore, lines of longitude are called meridians, which literally mean pie-shaped wedges (Figure 5).

Because meridians are not parallel to each other, the distance between adjacent meridians is different at the equator versus at the poles. For example:

- Meridians are located furthest away from each other at the equator.
- Meridians intersect with each other precisely at the poles.
- The distances between meridians becomes less with higher latitudes.

Figure 2. World map showing different geographic places along the same parallel.

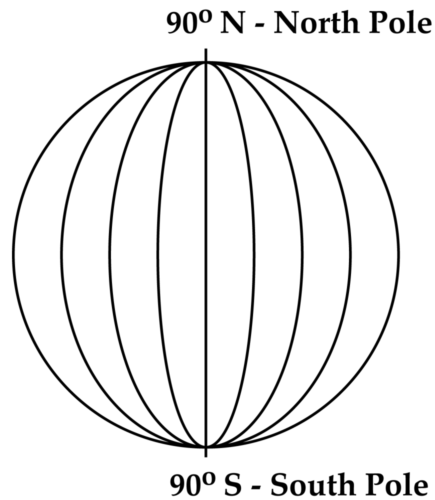

Figure 3. Globe showing meridians going from the north to the south pole.

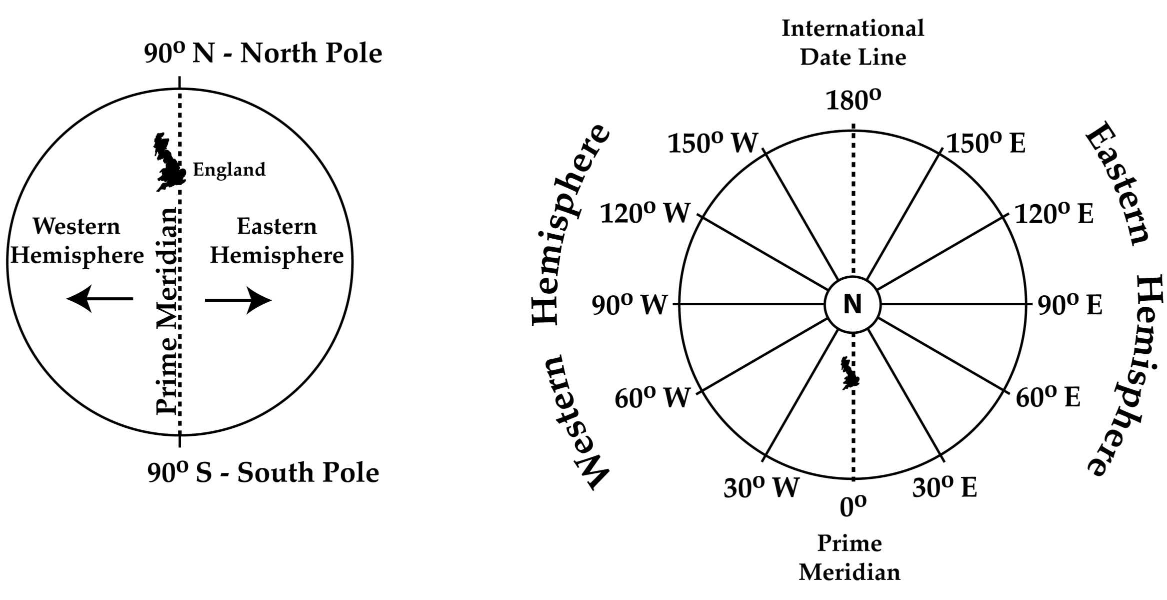

Figure 4. Globes with the prime meridian, western and eastern hemispheres labeled.

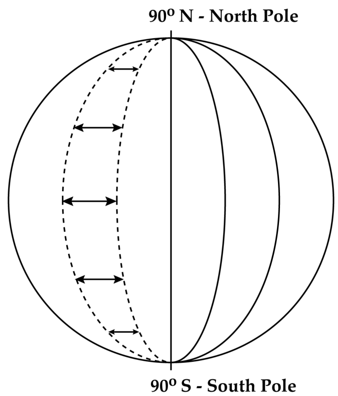

Figure 5. Diagram showing the pie-shaped nature of meridians (lines of longitude).

From the preceding discussion you should realize at this point that in the continental United States latitudes are always north and longitudes are always west (Figure 6). These facts result from the fact that the United States is north of the equator (in the northern hemisphere) and west of the prime meridian (in the western hemisphere).

Question: Can you accurately locate geographic features using degrees of latitude and longitude alone?

Answer: No

Observe the map of Texas (Figure 7). Note that there are large visible distances between individual parallels and meridians of latitude and longitude. Therefore, degrees can be further subdivided into smaller units called minutes.

$1^{\circ} =$ 60 minutes (‘)

Now you should realize that most maps that cover areas smaller than the whole world use both degrees and minutes. Again, latitude is always written first and longitude written second as with degrees first and then minutes (‘) as indicated below:

##º ##’ N, ###º ##’ W

Note that you always first begin by writing the lowest number for degrees of latitude and longitude. Let us work through determining the latitude and longitude of point E on Figure 7. Point E is between 28 and 29 º N latitude and 99 and 100 º W longitude. Therefore, the location of point E is

28º ##’ N, 99º ##’ W

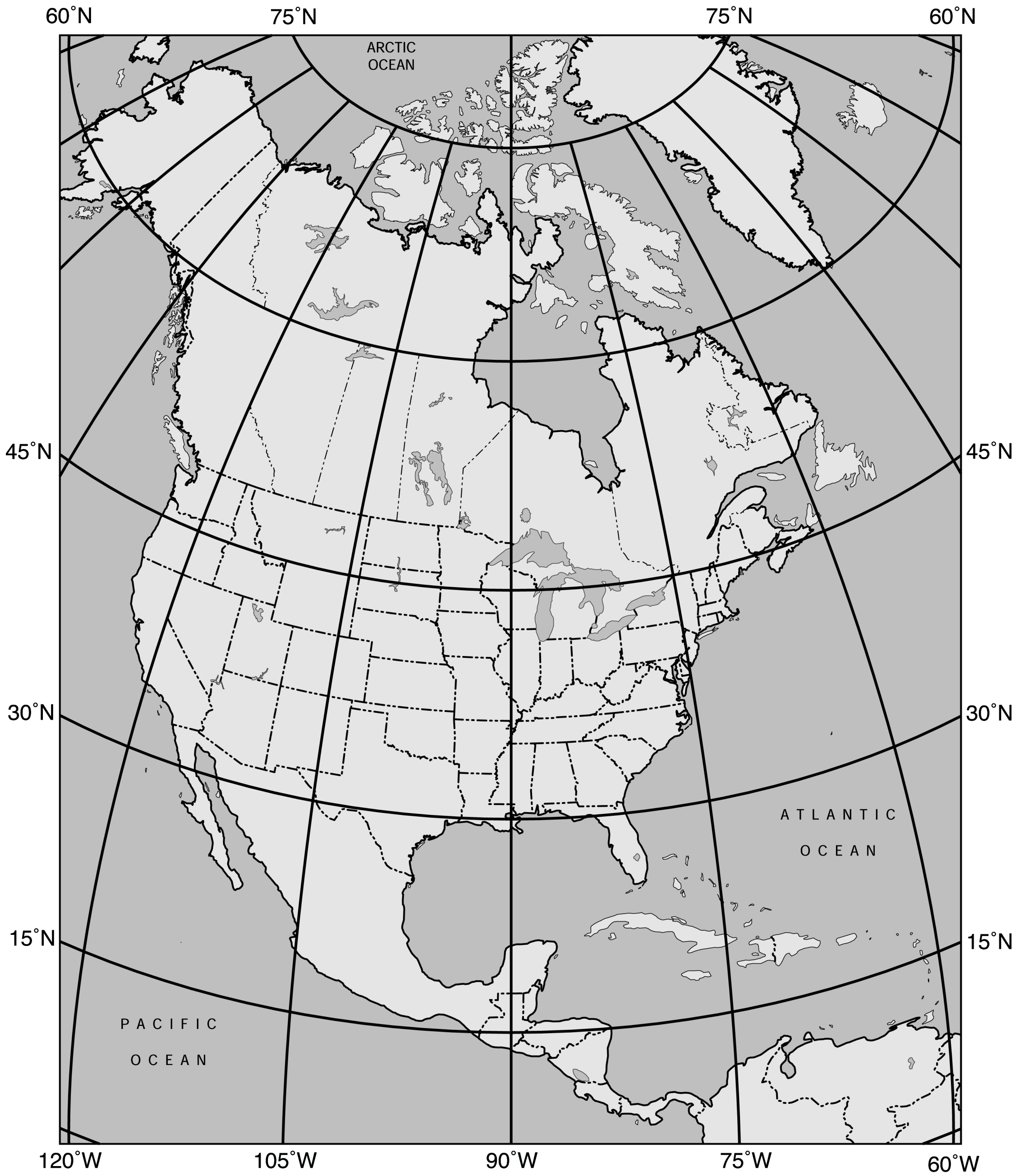

Figure 6. Map showing the continental United States in terms of latitude and longitude.

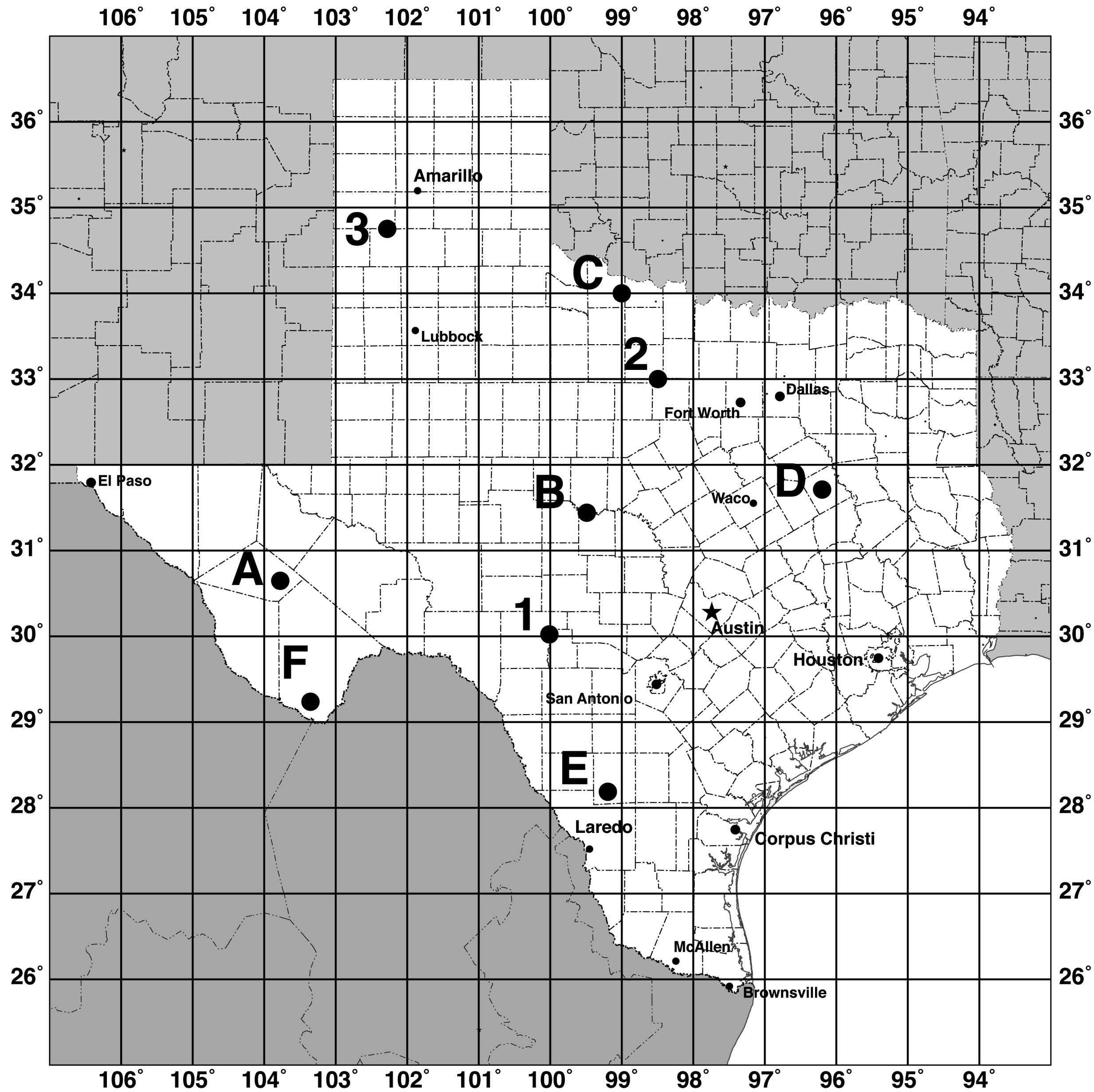

Figure 7. Map of Texas.

Minutes can be determined from interpolation between the parallels and meridians as is illustrated in Figure 8.

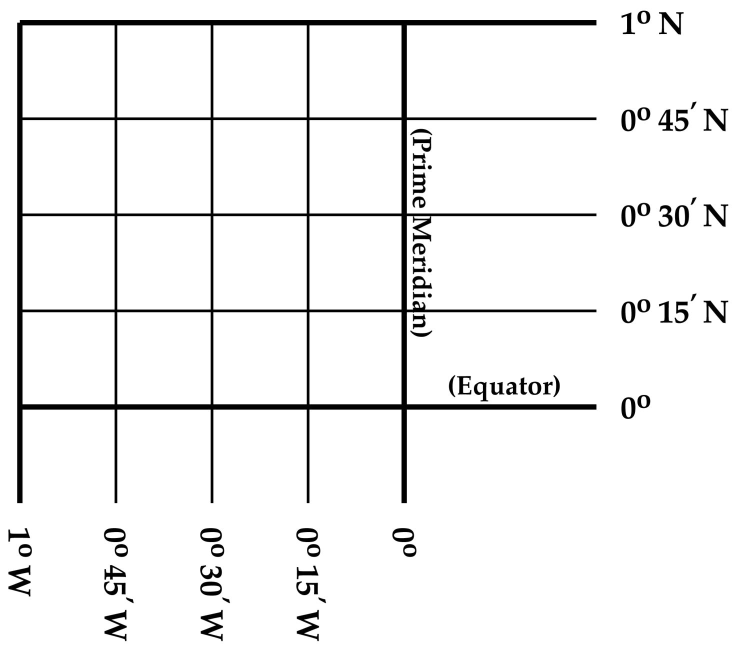

Figure 8. Diagram that shows how degrees are subdivided into minutes.

Point E on Figure 7 is closer to the 28° and 99 ° than the 29° or 100 ° parallel or meridian. Therefore, a reasonable interpolation of the location of point E is as follows.

28° 5' N, 99° 7' W

Locations given in degrees and minutes are accurate to within approximately one mile. To georeference one's location more accurately requires subdivision of minutes into seconds.

1' = 60 seconds (")

The United States Geological Survey has developed a nationwide series of quadrangle maps that cover small areas in great detail on the earth's surface (Figure 9). These maps can be purchased anywhere in the country and are also available on-line (http://store.usgs.gov/). The **standard quadrangle** map covers 7.5 minutes (or 7' 30") of latitude and longitude. Note that since a minute is approximately 1 mile, a quadrangle map covers roughly 7.5 miles of latitude.

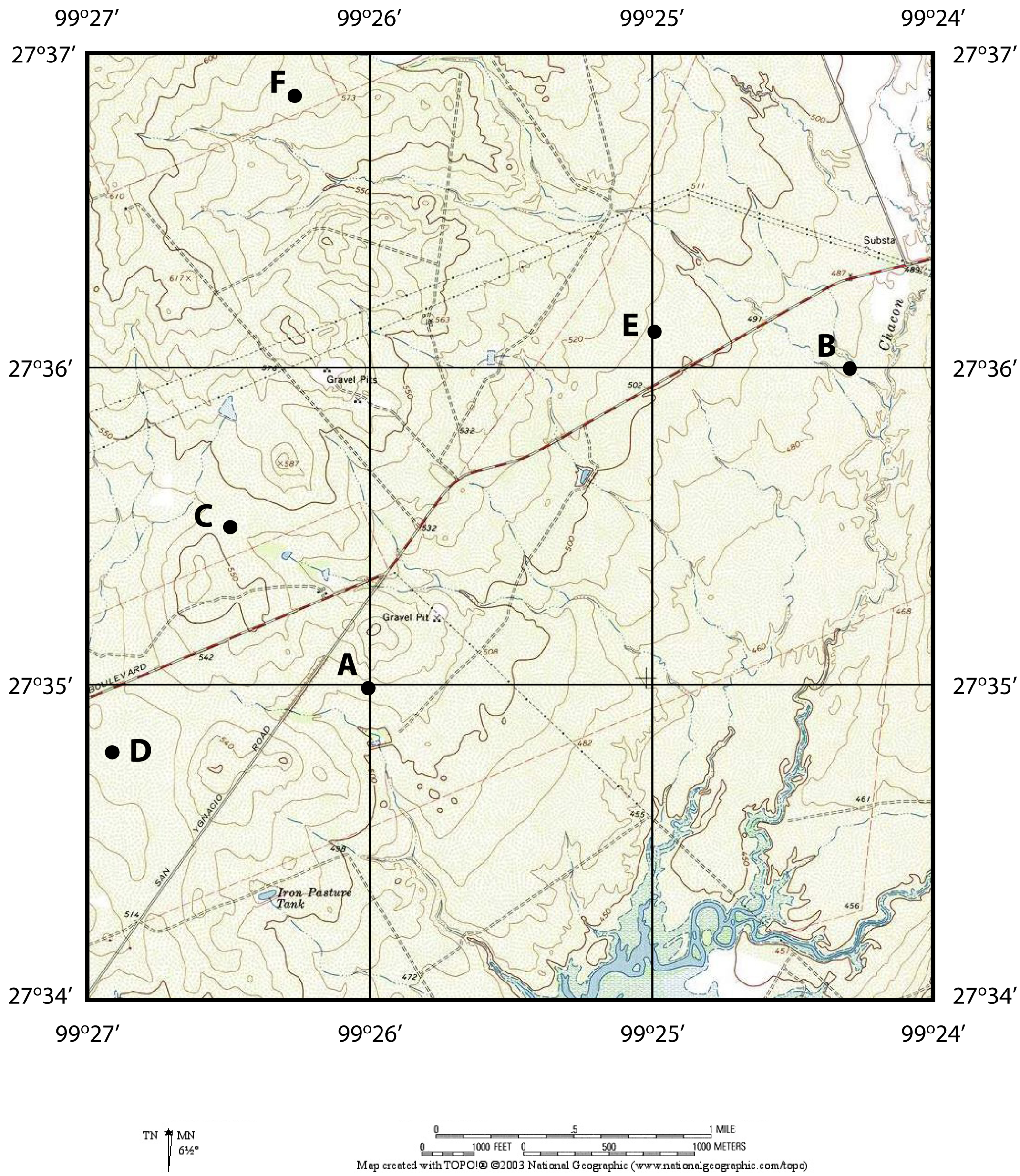

Figure 9. Map of a portion of the Laredo East Quadrangle.

Now you should realize that maps that cover very small areas use degrees, minutes, and seconds. Again latitude is always written first and longitude is second as with degrees, minutes, and seconds (") written as indicated below:

##º ##' ##" N,   ###º ##' ##" W

To write latitude and longitude with degrees, minutes, and seconds from a 7.5' quadrangle map realize that the degrees of latitude and longitude will be the same for the entire map. So all points on this map will have 27^{o} N latitude and 99^{o} W longitude. The only numbers that will change are the minutes and seconds. Let us determine the precise latitude and longitude of point E on Figure 9.

Note that you always first begin by writing the lowest number for degrees of latitude and longitude. Let us work through determining the latitude and longitude of point F on Figure 7. Point F is between 36 and 37 minutes of latitude and 26 and 27 longitude. Always select the lowest value. So we can determine the point F is

27^{o} 36’ ##" N, 99^{o} 26’ ##" W

Finally, to determine the seconds interpolation must be applied as described in the previous example. For latitude point F is close to the 37' parallel and the 26' meridian. Therefore, a reasonable interpolation of the location of point F is as follows.

27^{o} 36’ 54" N, 99^{o} 26’ 12" W

A final consideration is that GPS and Geographic Information Systems (GIS) commonly can report geographic coordinates in a base-ten format. Decimal degrees can be calculated by adding to the degree number the minutes divided by 60 and seconds divided by 3600 as illustrated below.

27^{o} 36’ 54" N   or $27 + (36/60) + (54/3600) = 27.615^{o}$

Note that N is omitted. By convention positive latitudes are north and negative are south. Likewise positive longitudes are west and negative are east. In case you do not want to do the math there are a number of on-line calculators that will do the work for you. Check out the following website:

https://www.latlong.net/degrees-minutes-seconds-to-decimal-degrees

Use the on-line convertor to determine the decimal degrees for point F longitude.

C. Planar Coordinate Systems

While geographic coordinates are commonly utilized in everyday applications this system of georeferencing has limitations in terms of determining distances and directions between locations on the earth. Planar coordinate systems overcome this difficulty because positions are defined in two-dimensional (x, y) space as distances in either meters or feet. This allows distances and directions to be easily determined through simple trigonometry. There are two commonly planar coordinate systems utilized in the United States, which include the **Universal Transverse Mercator (UTM)** and the **State Plane Coordinate System (SPCS).**

UTM System

The UTM system is universal in the context that it can be applied to any location on the earth except for polar regions within 6° of the north and south poles. The UTM system is based on dividing the Earth's surface into 60 zones that run from pole to pole. Each UTM zone covers an area of 6° of longitude. Zones are numbered 1 to 60 eastward from the international date line.

Check out the website below that describes the UTM system in more detail.
https://www.e-education.psu.edu/geog160/node/1914

Each UTM zone is subdivided along the equator into two halves, north and south. Every half of every UTM zone has a separate planar coordinate system in which distances are indicated in meters (m). The northern and southern halves of each UTM zone are a total of 10,000,000 m (10,000 km) in length as in illustrated Figure 10. East-west distances are measured from an origin that is located 500,000 m west of the center of the zone. This location ensures that all UTM coordinates are positive. Note that each UTM zone is widest at the equator and becomes narrower towards the poles. In the northern hemisphere the origin is located at the equator and in the southern hemisphere origin is located at 90° S (the south pole).

Let us practice with converting geographic coordinates into UTM coordinates. Again, there are on-line calculators that can facilitate this process. However, you have to have a knowledge of which UTM zone you are in to obtain meaningful results. First, examine the above URL, which includes a US Map indicating the location of UTM across the continental United States (Figure 2.6). We determine that most of Texas is in the **14N UTM** zone.

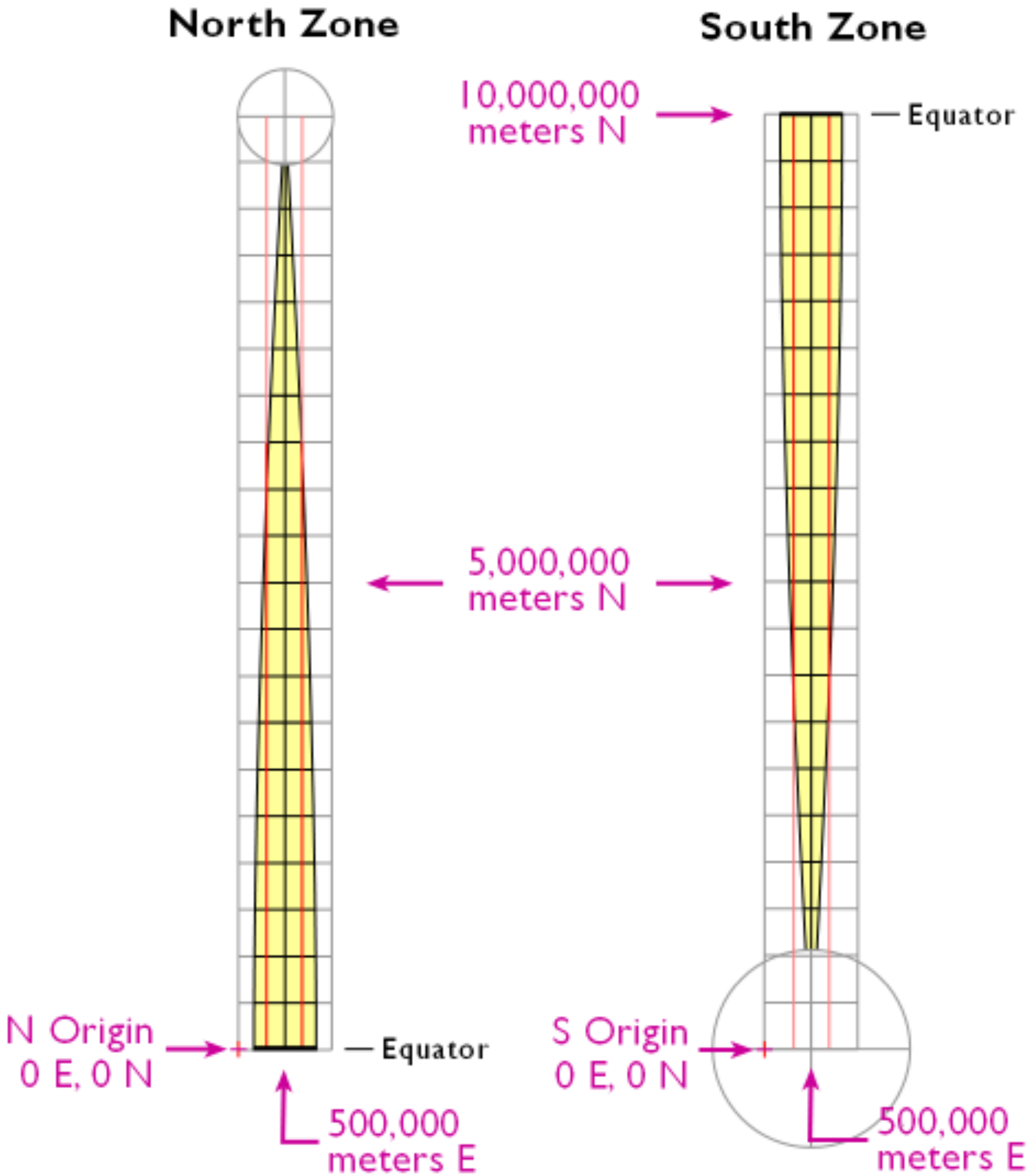

Figure 10. Diagram of an UTM zone. The yellow areas indicate locations on the Earth's surface that are referenced within the UTM zone. Illustration from DiBiase and others (2010). Nature of Geographic Information. The Pennsylvania State University. http://natureofgeoinfo.org

Now let us be more specific and determine the UTM coordinates for point F from the Laredo East quadrangle map (Figure 9) that we examined above. Go to the following on-line UTM calculator.

http://home.hiwaay.net/~taylorc/toolbox/geography/geoutm.html

Enter the geographic coordinates in decimal degrees. Be sure to select zone 14 otherwise the calculator will not return an answer. Note the two coordinates, an easting (measures E-W) and northing (measures N-S) relative to the origin are given, which are in meters. You can also convert from UTM back into geographic coordinates. Note that the easting value is close to 500,000 meters, which is near the center of the UTM 14N grid, which runs from 96 to 102^o W with a central axis at 99^o W. The northing is approximately 3,000,000 meters, which makes sense because Laredo is about 3,000 km north of the equator.

You need to be conformable with converting between geographic and UTM coordinates and will be asked quizzed on this later.

State Plane Coordinate Systems

Each state has its own system of plane coordinate systems. There are a total of 124 different plane coordinate systems across the United States. Most state plane zones are based on either a transverse Mercator projection (http://en.wikipedia.org/wiki/Transverse_Mercator_projection) or a Lambert conformal conic (http://en.wikipedia.org/wiki/Lambert_conformal_conic_projection), which we will discuss in detail next week. The choice between the two map projections is based on the shape of the state and its zones. States that are long in the east-west direction are typically divided into zones that are also long east-west. These zones use the **Lambert Conformal Conic** projection, because it is good at maintaining accuracy along an east-west axis. Zones that are long in the north-south direction use the **Transverse Mercator** projection because it is better at maintaining accuracy along a north-south axis.

Typically, a state plane system will have two **standard parallels** along which there is a minimum of map distortion (see example below).

North_America_Lambert_Conformal_Conic
Projection: Lambert_Conformal_Conic
False_Easting: 2500000.000000
False_Northing: 0.000000
Central_Meridian: -102.000000
Standard_Parallel_1: 17.500000

Standard_Parallel_2: 29.500000
Latitude_Of_Origin: 12.000000
Linear Unit: Meter

Question: Was the above coordinate system established for the United States or Mexico. Justify your answer?

The origin of each system occurs at the intersection of the center meridian and parallel located to the south of the zone (latitude of origin). Unlike the UTM system, eastings and northings (typically in feet in the US) at the zone origin are not 0, 0. However, eastings are defined as a positive number (false easting) sufficiently large to ensure that every easting in the zone will be a positive number.

In Texas there are five state plane zones as shown in Figure 11. There are also calculators that allow one to convert geographic coordinates into state plane coordinates and vice versa. Check out the following website:
http://www.ngs.noaa.gov/TOOLS/spc.html

Determine the state plane coordinates for point F from the Laredo East quadrangle map that we examined above.

Note the format that the data needs to be entered needs to be entered in decimal degrees.

Readings
DiBiase, D., 2014, Nature of Geographic Information Systems. Sections 2.10, 2.11, 2.12, 2.21, 2.22, 2.23, 2.25, 2.26, 2.27

Terms

Georeferencing	Latitude	Longitude	Decimal Degrees
Geographic Coordinate System	SPCS	Planar Coordinate System	UTM
Degrees, Minutes, Seconds	Equator	Prime Meridian	Standard Quadrangle
Transverse Mercator	Standard Parallels	Lambert Conformal Conic	

Concepts
Understand how latitude and longitude can be used to locate your position on earth
What is the difference between decimal degrees and degrees, minutes, seconds. How can you convert between these two formats.
What is the difference between a geographic and planar coordinate system.
Understand how the UTM system works

What is the significance of a standard parallel

In Texas, what type of map project is used for its SPCS? Do you know why?

Figure 11. Texas State Plane zones. From Texas Parks and Wildlife Department. http://www.tpwd.state.tx.us/publications/pwdpubs/media/pwd_mp_e0100_1070ag_08.pdf

HOMEWORK

1. Find two other (not listed above) converters that translate Geographic Coordinates into UTM. List the name of the website and URL.

2. Find two other (not listed above) converters that translate Geographic Coordinates into SPC. List the name of the website and URL.

3. Find the UTM eastings for the following longitudes. Enter 28.5° for latitude and for longitude enter values below.

-99.2000° ____________________ m   -99.0000° ____________________ m

-98. 8000° ____________________ m

4. Find the SPC eastings for the following longitudes. Enter 28.5° for latitude and for longitude enter values below.

-99.2000° ____________________ ft   -99.0000° ____________________ ft

-98. 8000° ____________________ ft

5. What plane coordinate system would be most appropriate for local mapping applications? Justify your answer.