Helpful Navigation Hints:
The Best of Harry Freimanis's Navigation Lectures*

Visual Scale. For visual scale reference in the area traveled through on a 7.5 minute topo, draw a line 1 mile long (2.6") and divide 1" of it into 10 parts, each 1/10" long. These building blocks of 1/10" equal 200 feet exactly. This scale is helpful to estimating distance in the field.

Color Highlighting. Highlight or color-dot prominent high points on the topo that are most likely to be visible to the eye. This allows for easier N-S alignment of the topo and facilitates terrain recognition.

Map Orientation in the Field. When using a topo for terrain recognition, always have it N-S aligned. To keep the topo easily N-S aligned, draw a line on the ground with a hiking pole or your boots. Alternatively, set your hiking pole on the ground point aligned to N-S. The top N-S lines can then be quickly aligned with the N-S line on the ground.

Man-Made Features. Man-made features can and will change over time, but even a recently revised topo will not show most of the latest additions and deletions. Example: The water tank you see in the field may not be shown on the map, and a water tank on the topo may not be in the field anymore.

Take Three Bearings. Take a set of three independent bearings of the same object. The resulting spread in degrees is a measure of your compass use accuracy. The average of your three bearings will tend to be more accurate than any single reading. Because landmarks are some distance away, a very accurate compass bearing might be a degree or two off. The following table shows how many feet off target you will be as a result of certain bearing errors at selected distances:

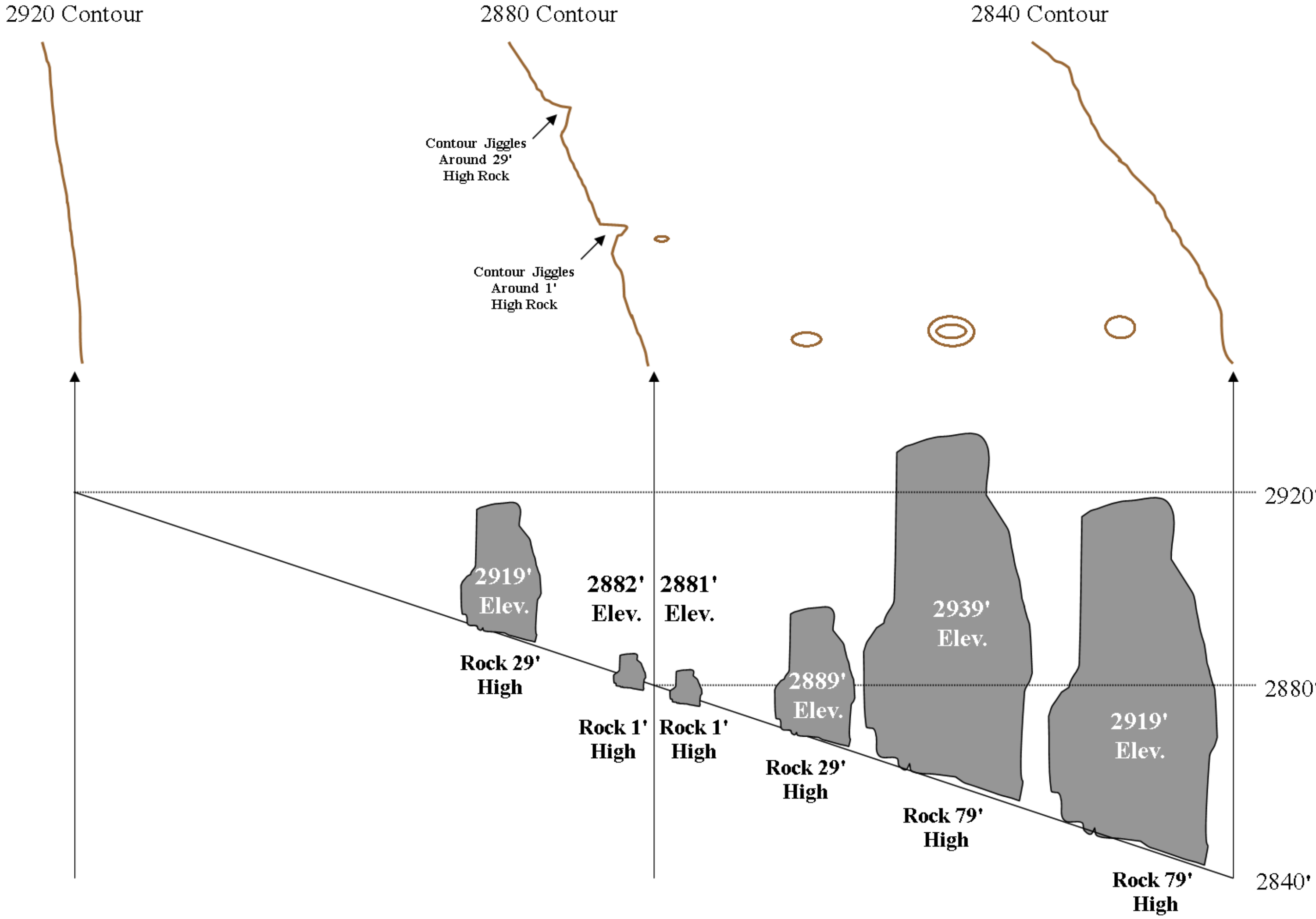
Degree Error	0.5 Mile	1.0 Mile	2.0 Mile	3.0 Mile
1°	46'	92.4'	185'	277'
2°	92'	185'	370'	554'
3°	138'	277'	554'	832'

Keep Compass Level. You will minimize large bearing errors if you keep your compass level. This keeps the needle from rubbing against the capsule.

* Harry Freimanis was the LTC Navigation Chair for two decades and recipient of the Angeles Chapter's highest outings service award — the Chester Versteeg Outings Plaque. He died in 2010.

Contour Lines. A single closed contour line can represent a land form object (i.e., rock formation) anywhere from one foot in height to 79 feet in height. Whether a rock pile as shown on the topographic map will be represented by one or two contours depends on where the contour lines (e.g., 2880' contour line) intersect the rock formation as shown in the diagram below.

A downhill jiggle in a single contour line usually represents a contour line encountering a rock formation as it moves around the rock on the downhill side.



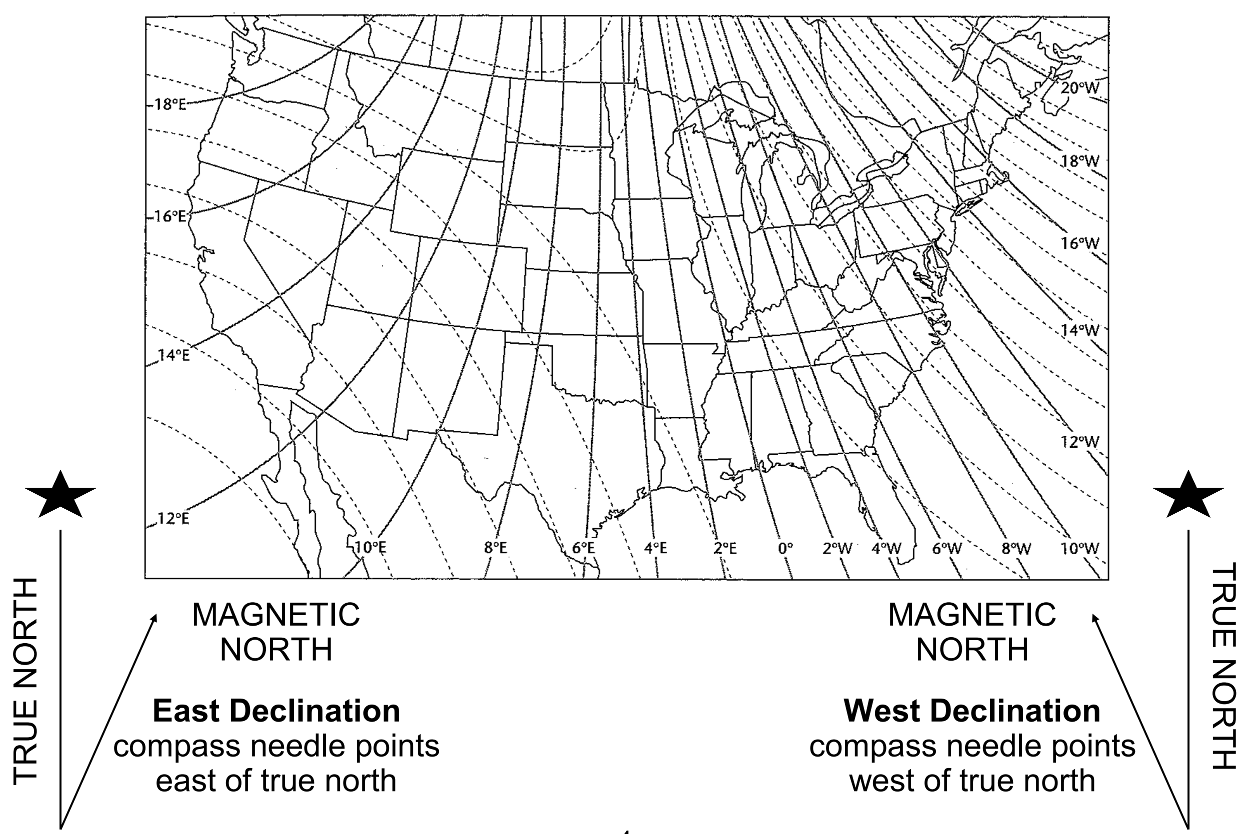
Compass *De*clination. The vertical edges of topographic maps point to the geographic north pole, which is called **true north**. The difference in bearing degrees between the geographic north pole and where the horizontal magnetic needle points to is called magnetic declination. This varies greatly in different parts of the earth, causing the magnetic needle to point in directions often unrelated to the location of the north magnetic pole. This is the result of chaotic magma circulation near the core-mantle boundary deep within the earth. In the western part of the United States, the compass needle will point to the east of **true north**; in the Eastern part it will point to west of **true north**. The difference between where your compass needle points and **true north** is called **magnetic declination**.

The illustration below shows the approximate lines of magnetic declination throughout the United States. In the contiguous United States, declination ranges from 21° east in northern Washington to 19° west in northern Maine. The declination in the Los Angeles area is 13° east.

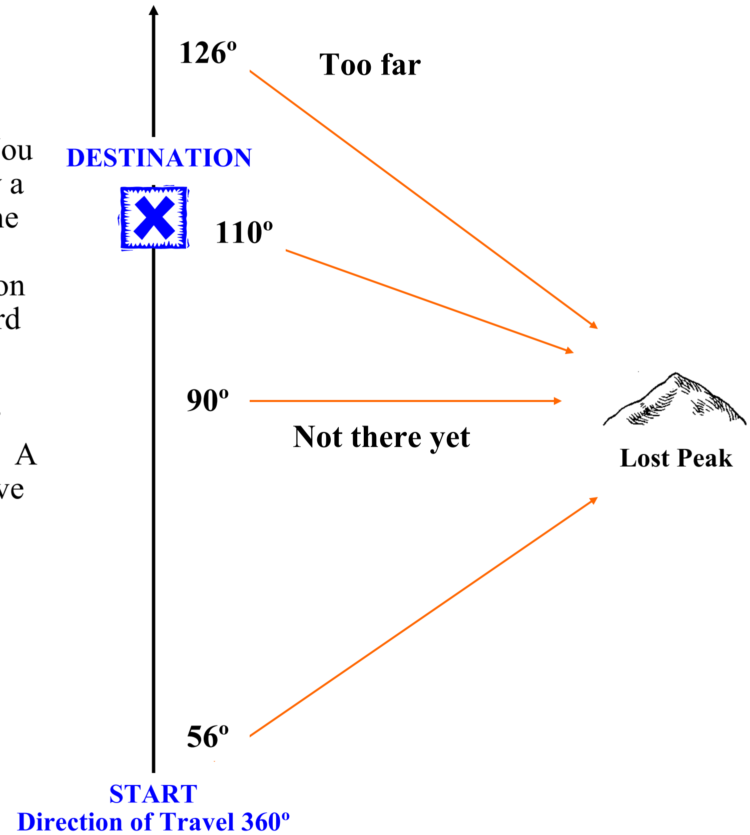
The magnetic north pole has been migrating to NNW by about 25 miles per year. This rate of change translates to a change of about 5' per year in Los Angeles or about 1° every 12 years! This is not a predicator of the future rate of change. The historical average has been about 1° every 25 years. Older maps may have declination information that is outdated and not correct. Current declination information can be obtained from the National Geophysical Data Center:

http://www.ngdc.noaa.gov/geomag-web/#declination

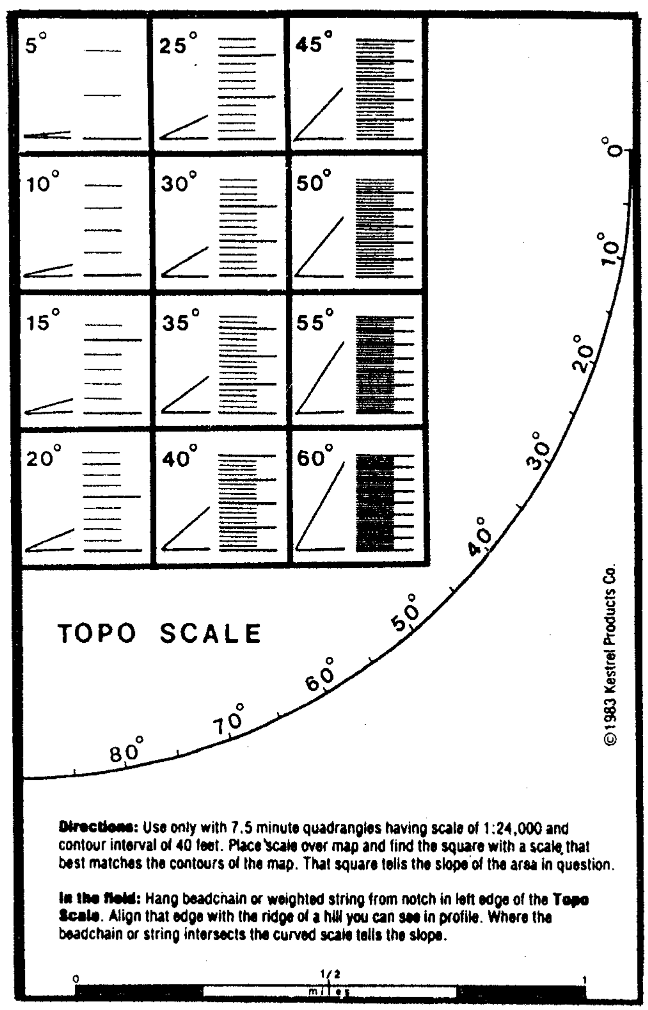
To use a map and compass together accurately, you must use current magnetic declination. It is best and most accurate to use a compass with a mechanical declination adjustment. Other methods include use of an inaccurate "tape arrow" or adjusting the magnetic direction reading mentally – not easy when plotting is required.



Using Cross-Bearings to Measure Progress. You can measure progress along your line of travel by a cross-bearing to a landmark along the way. In the example, you determine from your map that the bearing to Lost Peak is 56º at your starting location and 110º at your destination. As you travel toward your destination, you can measure your progress and also determine if you have gone too far. For example, you take a bearing along the way of 90º and know you have not reached your destination. A bearing of more than 110º would indicate you have gone too far.

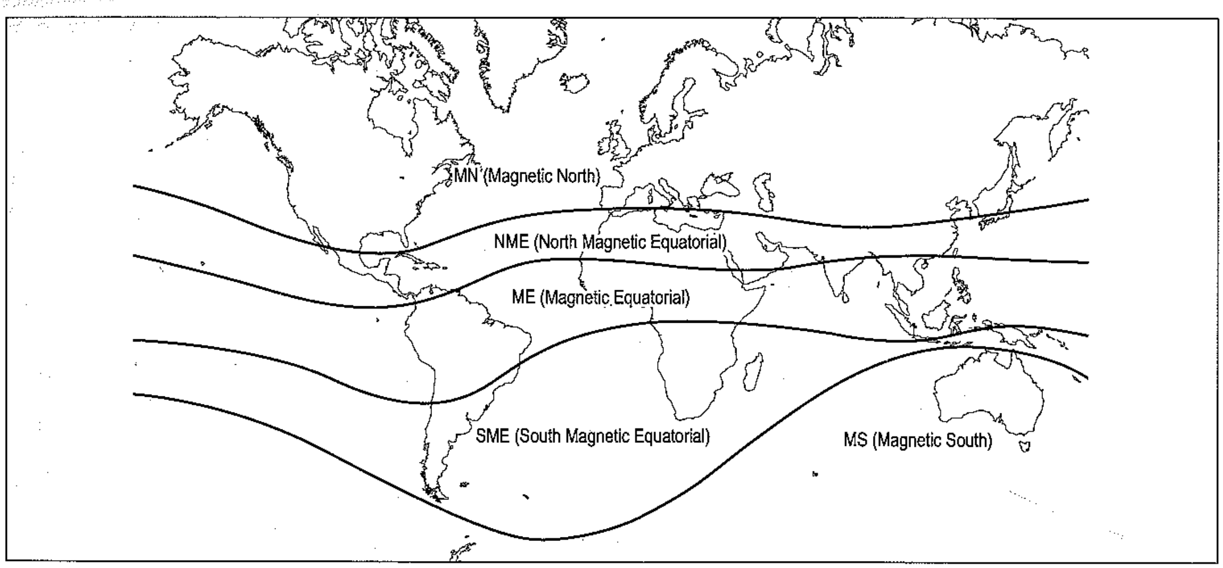


Slope. A useful tool for determining slope is the Topo Scale overlay distributed at navigation noodles. When it is overlaid on any 7.5 minute topo with a contour interval of 40 feet, select the best spacing match to determine the angle of slope on the topo.



Compass *In*clination. The earth's magnetic field has another major effect on compasses, a vertical component caused by its three-dimensional center deep inside the earth's mantle. The needle attempts to follow the magnetic flux lines as they twistingly converge downward toward the area of the magnetic pole. Around the pole the magnetic flux lines and a simple magnetized needle would tend to point vertically. Far from the magnetic north pole in Southern California, the north end of a simple magnetic needle (typically red) of the compass will tend to point northward below the horizon at about 59º. ***This is called inclination.*** However, we are not even aware of it when using a compass.

To counter this dip, the needle in a compass is counterweighted at the south end (usually white or black) so that it balances to a level position, and points to the horizontal component of the magnetic pole. The inclination changes in different regions of the earth, as shown in the diagram below. Our compass would dip some amount in Australia, and vice versa, so compasses for the five different regions shown below have different counterweights.



Suunto has developed a patented **Global Needle** that will perform perfectly with needle tilts of up to 20 degrees. This allows a single compass to be used effectively in all 5 of the earth's compass zones. The compass needle is not magnetic, and always sits horizontally on a magnetic gimbal assembly which is magnetic. The gimbal assembly is designed to point to the actual magnetic pole. Relative changes in the 3-dimensional location of the magnetic pole are thus isolated from the needle in all parts of the non-polar world.

Although principally a boon to world travelers, the global needle does have one major advantage for local navigation. With traditional compasses, you must hold the compass level to achieve accurate bearings. This is sometimes difficult when you are moving or are taking bearings to a valley far below you or to a peak far above you. With the global needle's unique ability to handle tilts up to 20 degrees, you can achieve accurate bearings when your compass is slightly tilted.

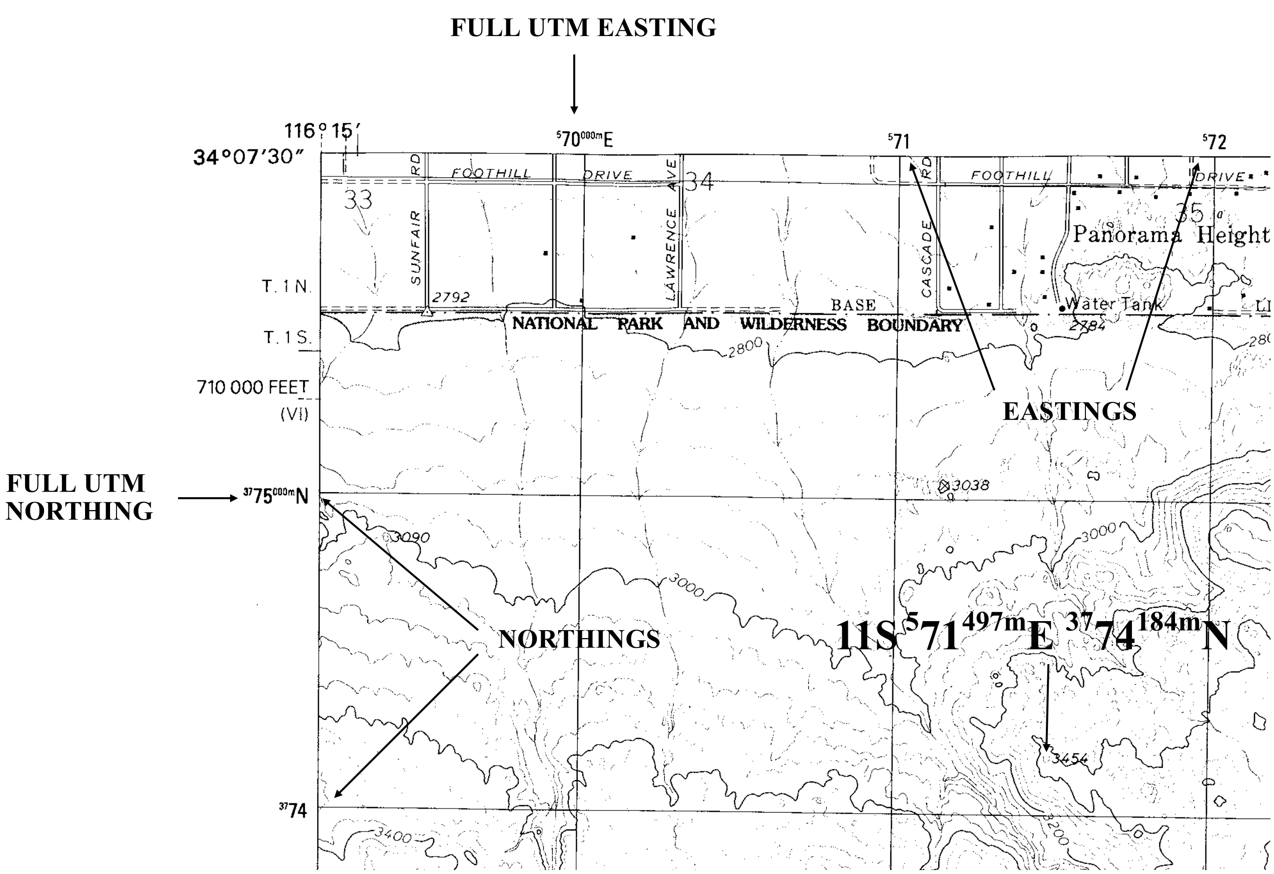
UTM Grids and Coordinates. The UTM grid system helps you find the coordinate for any point on the map. This system is particularly helpful when using a GPS device.

All USGS topographic maps printed in the last 30 years include UTM grid tick marks on the margin of the map. Corresponding tickmarks are on both the top, bottom, and side margins of the map. Some maps are printed with a fine-lined UTM grid. However, many USGS 1:24,000 scale topographic maps do not have gridlines printed on them. For those maps, you can add a UTM gridline by drawing lines between corresponding tickmarks.

The map below is the northwest corner of the Indian Cove quadrangle (7.5 minute series, scale 1:24,000). It is printed with UTM gridlines. The numbers along the top of the map (and bottom) are called eastings, which provide an east-west position. The numbers on the left side of the map (and the right side) are called northings. They give you a north-south position. The UTM grid is based on meters and the gridlines are always 1 kilometer (1000 meters or .62 mile) apart on 7.5 minute maps. It is easy to estimate distance because the distance between each gridline is the same.

Location in the UTM system is defined by the coordinates of the point, giving the easting first and then the northing. The convention of east (right) first, then north (up) can be remembered by the mnemonic “read right up.”

The full UTM coordinate for Peak 3454 is shown on the map and explained on the next page.



Overview of Eastings, Northings, and UTM Coordinates.

Eastings

Increasing easting numbers means you are going east.
An example of a full easting coordinate number: ^{5}**70**^{000m}E.
^{5}**71** is a shorthand method of describing ^{5}**71**^{000m}E; ^{5}**72** is a shorthand for ^{5}**72**^{000m}E
Distance between ^{5}**70**^{000m}E and ^{5}**71** is 1000 meters (1 kilometer).
Distance between ^{5}**71** and ^{5}**72** is 1000 meters (1 kilometer).
The last three numbers stand for number of meters east of the easting gridline:

- ^{5}**71**^{100m}E indicates that the coordinate is 100 meters east of the ^{5}**71** gridline.
- ^{5}**71**^{831m}E indicates that the coordinate is 831 meters east of the ^{5}**71** gridline.

[What the numbers mean: The world is divided into 60 UTM zones, each 6° wide. The meridian (center) of each zone is assigned the value ^{5}**00**^{000m}E. Eastings within each zone will range from ^{1}**66**^{640m}E in western area of the zone to ^{8}**33**^{360m}E in the eastern area of the zone. An easting of ^{5}**70**^{000m}E means that it is 70,000 meters east of the zone meridian (570,000 - 500,000 = 70,000), whereas an easting of ^{4}**30**^{000m}E means that it is 70,000 meters west of the zone meridian (500,000 - 430,000 = 70,000).]

Northings

Increasing northing numbers means you are going north.
An example of a full northing coordinate number: ^{37}**75**^{000m}N.
^{37}**74** is a shorthand method of describing ^{37}**74**^{000m}N; ^{37}**73** is a shorthand for ^{37}**73**^{000m}N
Distance between ^{37}**75**^{000m}N and ^{37}**74** is 1000 meters (1 kilometer).
Distance between ^{37}**74** and ^{37}**73** is 1000 meters (1 kilometer).
The last three numbers stand for the number of meters north of the northing gridline:

- ^{37}**74**^{100m}N indicates that the coordinate is 100 meters north of the ^{37}**74** gridline.
- ^{37}**74**^{831m}N indicates that the coordinate is 831 meters north of the ^{37}**74** gridline.

[What the numbers mean: For locations north of the equator, values range from ^{00}**00**^{000m}N to ^{93}**34**^{080m}N. A northing value of ^{37}**75**^{000m}N means that the point lies 3,775,000 meters north of the equator.]

UTM Coordinates

The form of a complete UTM coordinate is zone, easting and northing.
The zone is printed on the map. For the Indian Cove map, it is zone 11.
The Military Grid Reference System divides each zone horizontally into 8° sections and assigns a letter to them. For the Indian Cove map, it is zone "S."
The complete UTM coodinate for Peak 3454 is:

11S ^{5}**71**^{497m}E ^{37}**74**^{184m}N. This gives the UTM coordinate to within a one meter square area.

There are a number of ways to abbreviate this coordinate:

Drop the zone number:	^{5}**71**^{497m}E ^{37}**74**^{184m}N
Drop the superscript:	**71**^{497m}E **74**^{184m}N
Accuracy to within 10 meters square:	**71**^{49}E **74**^{18}N
Accuracy to within 100 meters square:	**71**^{4}E **74**^{1}N

Other conventions used to abbreviate this same coordinate:

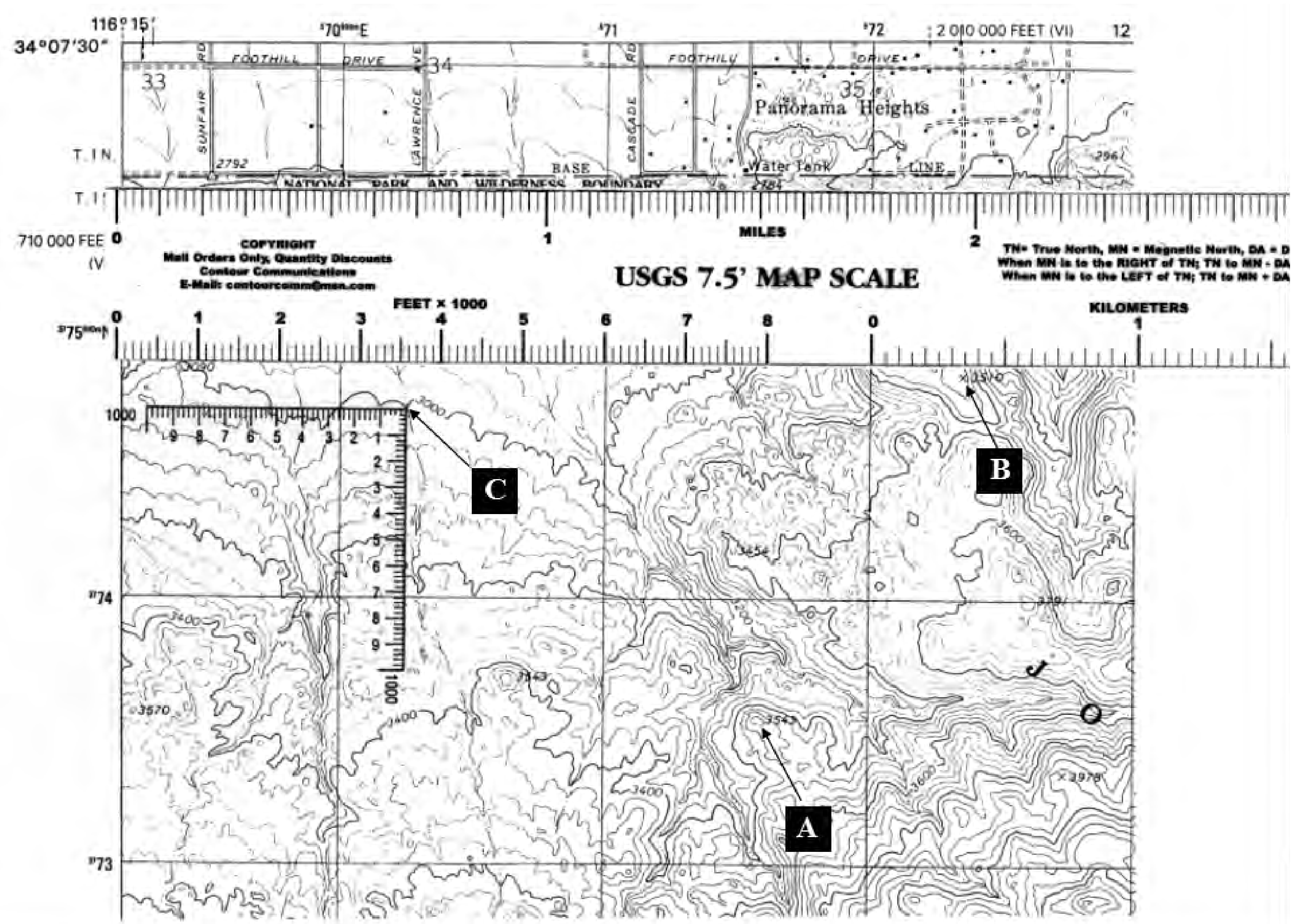
Six Digits (accurate to within 100 meters square):	714 741
Eight Digits (accurate to within 10 meters square):	7149 7418
Ten Digits (accurate to within 1 meter square):	71497 74184

Finding UTM Coordinates. There are several ways to find UTM coordinates:

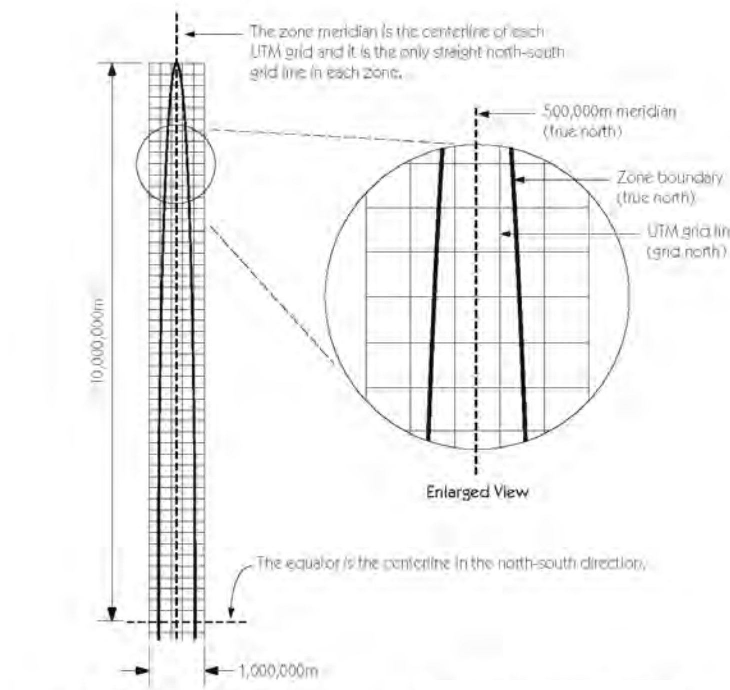
Visually: You can obtain an accurate coordinate to within about 100 meters simply by using your eyes. On the map below, Peak 3543 (**A**) looks about six-tenths of the way between eastings $^{5}\mathbf{71}$ and $^{5}\mathbf{72}$ and about halfway between northings $^{37}\mathbf{73}$ and $^{37}\mathbf{74}$. Therefore, the coordinate of 11S $^{5}\mathbf{71}^{600m}$E $^{37}\mathbf{73}^{500m}$N would be accurate to within 100 meters. The *TOPO!* computer program gives the coordinate as 11S $^{5}\mathbf{71}^{588m}$E $^{37}\mathbf{73}^{545m}$N.

With a Map Ruler: The map ruler used below gives 50 meter increments and accuracy will be between 25-50 meters. On the map below, Peak 3510 (**B**) is 350 meters east of easting $^{5}\mathbf{72}$. Using the ruler (not illustrated), the peak is 850 meters north of northing $^{37}\mathbf{74}$. Therefore, the coordinate of 11S $^{5}\mathbf{72}^{350m}$E $^{37}\mathbf{74}^{850m}$N would be accurate to within 50 meters. *TOPO!* gives the coordinate as 11S $^{5}\mathbf{72}^{348m}$E $^{37}\mathbf{74}^{841m}$N.

With a UTM Ruler: The corner of this special ruler is placed on the target location. The horizontal scale measures the easting; it is found by where the scale intersects the easting gridline. The vertical scale measures the northing; it is found where the scale intersects the northing gridline. The UTM Ruler used below is in 20 meter increments and can produce accuracy to within 10-20 meters. On the map below, Point **C** is where an intermittent stream crosses the 3000 foot index contour line. It is 260 meters east of easting $^{5}\mathbf{70}$ and 720 meters north of northing $^{37}\mathbf{74}$ resulting in coordinate of 11S $^{5}\mathbf{70}^{260m}$E $^{37}\mathbf{74}^{720m}$N. *TOPO!* gives the coordinate as 11S $^{5}\mathbf{70}^{257m}$E $^{37}\mathbf{74}^{727m}$N.



UTM Lines as North-South Lines. Only the central meridian of each UTM zone (^{5}**00**^{000m}E) is True North (TN). This means that the UTM gridlines east or west of the central meridian of each UTM zone are not TN. The farther away from the central meridian, the bigger the difference between the UTM gridline and TN. UTM gridlines vary off TN up to 2.5◦ to the west of TN for areas west of the central meridian and up to 2.5◦ to the east of TN for areas east of the central meridian.



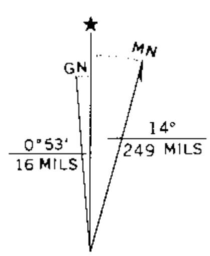
One Zone With UTM Grid Overlay (Southern Hemisphere Not Shown)

Although the UTM gridlines other than the central meridian are not TN, there is a way to use them in lieu of drawing N-S lines on your map.

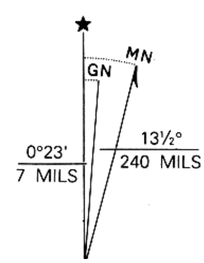
UTM lines can be used in lieu of N-S lines only if you adjust the compass declination to take into account the difference between TN and Grid North (GN). As illustrated below, the margin information on your topographic map shows the difference between TN and GN. Making the adjustment is simple. First, determine the current magnetic declination for your area as described on page 4 above. Second, look at the map and find the difference between TN and GN. (Unlike the magnetic declination, the difference between TN and GN does not change over time.) Third, adjust the declination on your compass as follows in areas with East Declination (in the eastern United States with West Declination, the rules are reversed):

If GN is west of TN add the difference to the magnetic declination

If GN is east of TN, subtract the difference from declination



Typical margin information for Santa Monica Mountains. Add 1 degree to current declination



Typical margin information for Joshua Tree. Subtract 1/2 degree from current declination

The current declination in the Indian Cove area is 12◦ 25' E. Thus, to use your compass with the UTM lines as N-S lines, your compass declination should be set at 12◦, since GN is 0◦ 23' east of TN as indicated on the Indian Cove 7.5 Minute Map.

Datums. You need to know which map datum you are using. Although much could be written about map datums, all you really need to know is that there are many different mathematical models for representing the earth called map datums. Most consumer GPS devices for hiking allow the user to select from over 100 different map datums – from Adindan to Zanderij. For travel in the continental United States, you only need to know about three map datums.

Most GPS devices default to a datum called the World Geodetic System of 1984 (WGS84). As the name implies, this datum was developed to have worldwide application and was an essential component in developing the global positioning satellite system. Older map datums were limited because they only covered certain geographic areas. Most USGS topographic maps were produced before WGS84 was launched and use the North American Datum of 1927 (NAD27). The newer US Topo Series uses the North American Datum of 1983 (NAD83), which is virtually identical to WGS84.

The most important thing to remember about map datums is that your map and GPS should use the same datum. Therefore, if your USGS 7.5′ map uses NAD27, your GPS device should be set to NAD27. The GPS menu will give you up to 11 different variations of NAD27. For the continental United States, select NAD27 CONUS, which stands for the CONtinental US.

Problems will arise if you are not using the right map datum. The same UTM coordinate will take you to different locations depending on which map datum you are using. As illustrated by the map below, the NAD27 location is 194 meters (636 feet) north of the WGS84 location and 79 (259 feet) meters west of it. The locations are in different drainages separated by a large rock formation.

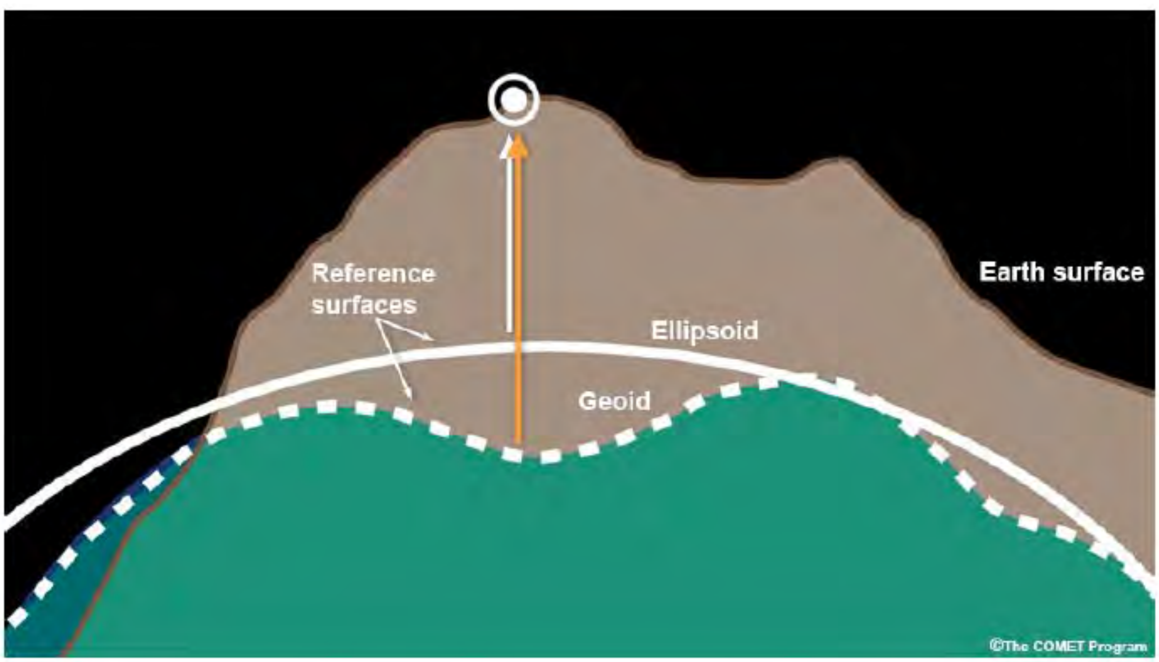
Using the wrong map datum can lead you to the wrong place if you are following coordinates given to you by someone else. If you are summoning search and rescue, knowing the map datum will result in a quicker response to your location. The best way to make sure that you and others are using the same datum is to always precede a coordinate with the map datum used.

GPS and Elevation. Geodesy, as defined in 1880 by Friedrich Robert Helmert, is the "science of the measurement and mapping of the Earth's surface." Without exploring the scientific complexity of geodesy, it is sufficient to note that elevation is determined by a reference point and that there are different reference points used to determine elevation.

Topographic maps and GPS use different reference points. The United States Geological Survey provides the following explanation:

> GPS heights are based on an ellipsoid (a mathematical representation of the earth's shape), while USGS map elevations are based on a vertical datum tied to the geoid (what we commonly call "mean sea level"). GPS elevations can disagree with map elevations by +/-400 feet. (https://www2.usgs.gov/faq/categories/9758/3023)

Elevations determined by reference to an ellipsoid are referred to as ellipsoidal elevation, whereas elevations determined by reference to the geoid are referred to as orthometric elevation. The illustration below shows the difference between the ellipsoid and geoid.

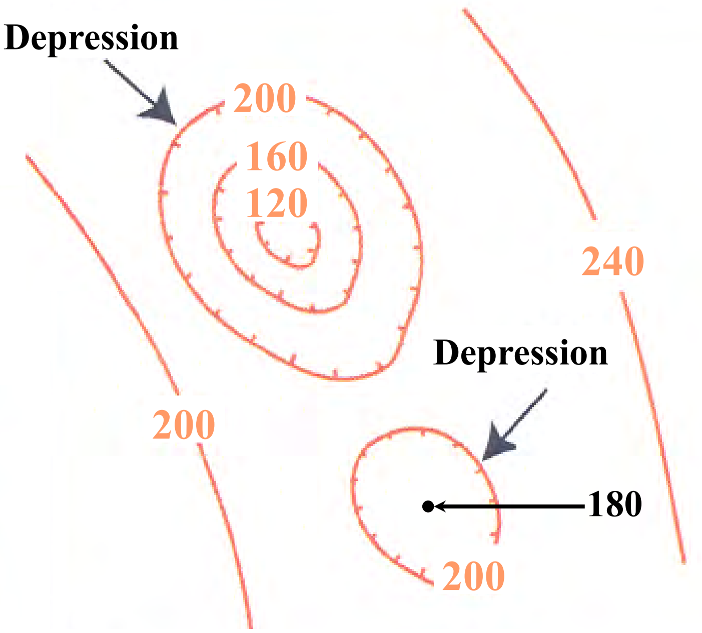


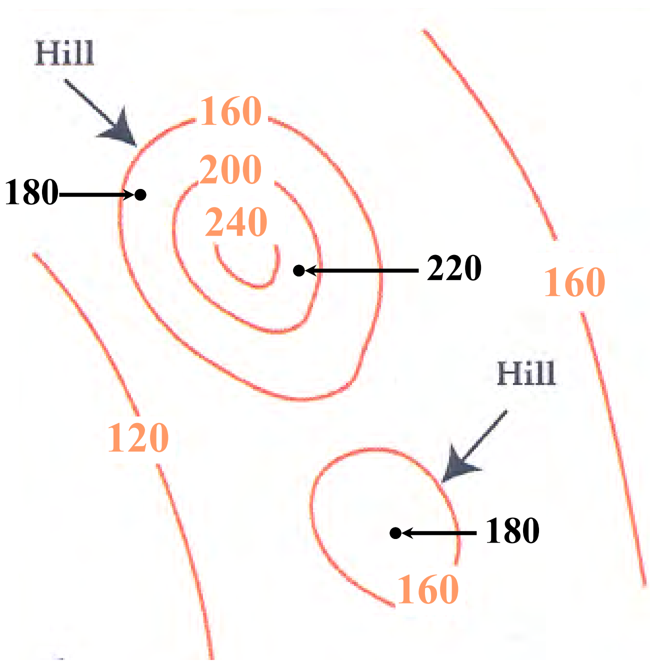
Throughout the coterminous United States, the geoid is below the ellipsoid. This means that elevations determined by a GPS device will be lower than elevations shown on our topographic maps. In those places where the geoid is above the ellipsoid, GPS elevation will be higher than the orthometric elevation shown on the map.

It is important to note that reference models are regularly updated. For example, the North American Datum of 1927 was based on Clarke 1866 ellipsoid and differences between the geoid and ellipsoid were no greater than 12 meters in the United States. By contrast, the North American Datum of 1983 is based on the GRS80 ellipsoid and differences can be up to 53 meters in the United States. A new reference datum for the United States will be released in 2022.

Elevation Between Contour Lines. For the LTP Navigation Exam, the following rules apply as illustrated in the diagram below:

- Any point between adjacent contour lines is 20 ft elevation away from each of the contour lines
- Any point inside a closed contour line is 20 ft above it.
- When a depression occurs between two contour lines, the elevation of a single depression contour line is the elevation of the adjacent lower contour line
- Additional depression contour lines, within the depression, are each one contour line of elevation lower
- The elevation at the bottom of a depression is taken to be one half of a contour interval below the lowest depression contour line





Caution:
These rules result in estimates that may be different from actual conditions. For example the elevation at center of the closed contour to the left might range in elevation from 161 to 197 feet.

A note on accuracy standards. USGS Topo accuracy standards require that 90% of the well-defined points (markers, monuments, road intersections, etc) on a topo meet the following standards:

<u>Horizontal</u> = within 1/50 inch [Since 1/10 inch = 200 ft, 1/50 inch = <u>40 ft distance</u>]
On a Topo map, trying to discriminate location to 1/50th of an inch is impossible

<u>Vertical</u> = 1/2 elevation difference between adjacent contour lines [1/2 of a 40 ft contour interval = <u>20 ft elevation</u>]

Squiggle Factor for Terrain Difficulty. A "squiggle factor" takes into account terrain or trail difficulty in trip planning. Simply stated, some terrain takes longer to travel over than others. Just as the Naismith rule recognizes that hiking uphill adds extra time over hiking on level ground, the squiggle factors recognize that hiking over rougher terrain takes longer. Terrain features that slow our progress include: bushes and trees, sandy ground in desert, washes and beaches, wet or slippery ground (including scree slopes, pine needles, and wet rock), rock strewn ground and boulder covered ground. Squiggle factors can range from 10 to 15% for desert travel to 100 to 800 % for difficult bouldering.

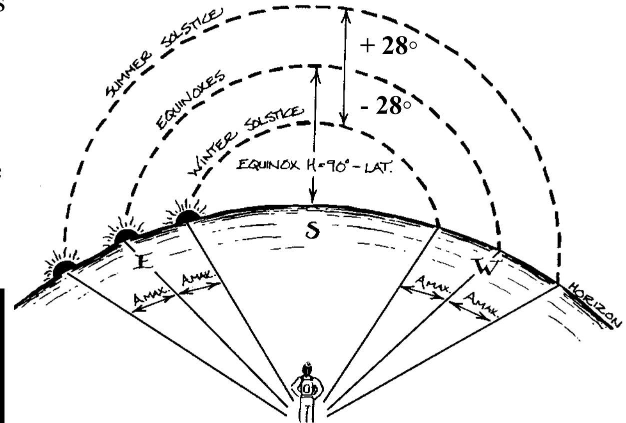
The following are some range estimates to be added to Naismith trip legs:

Typical desert terrain, 10 to 15%
Wooded terrain, 10 to 20%, with slope 20 to 40%
Wet and rock stewn ground, 10 to 30%
Sandy wash or beach, 20 to 40%
Easy bouldering, 25 to 50%
More difficult bouldering, 100 to 800%

Squiggle factors are rational estimates, never precise, and are difficult to select until you have seen the ground you will be hiking on. However, if you don't use them in trip planning, you will underestimate your time estimates, which could result in being unable to safely achieve or return from your destination.

Altimeters. Use of an altimeter is not part of the Angeles Chapter's I/M navigation checkoff. However, a good understanding of the altimeter will provide you with an important navigation tool; it is required for the E-level checkout. To use an altimeter effectively requires an understanding of how it functions, what affects its readings, and what its accuracy limitations are. Changing weather will effect the accuracy of an altimeter. In addition, local temperature differences from International Standard Atmosphere – the standard by which altimeters are calibrated – will effect the altimeter's accuracy. Despite many variables, altimeter accuracy can be achieved and maintained by resetting the instrument whenever the user is at an identifiable location on the map. The more frequent the reset, the more accurate the altitude reading. More information can be found in the LRB.

Sun. Generally the sun rises in the east and sets in the west. On the vernal and autumnal equinoxes, the sun will be due east (90◦ bearing) at sunrise and due west (270◦) at sunset. At our latitude, the location of the sun will change by 28◦ between the equinox and the solstice, amounting to about two hours of daylight difference.

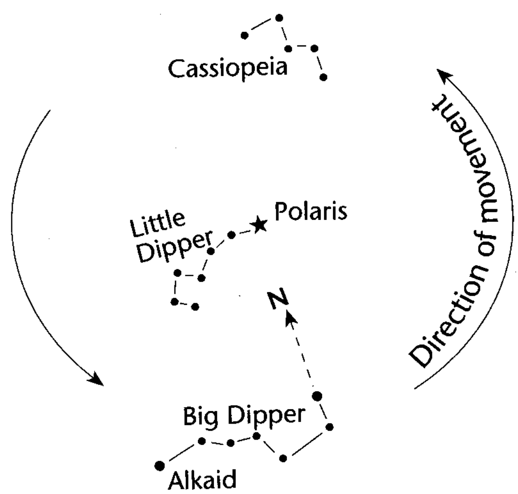


Vernal Equinox:	March 20, 2019
Summer Solstice:	June 21, 2019
Autumnal Equinox:	September 23, 2019
Winter Solstice:	December 22, 2019

When the sun is highest around local noon, the shadow of a vertical stick points to the north. Local noon is the midpoint between sunrise and sunset and changes by one hour with daylight savings time (spring forward, fall back).

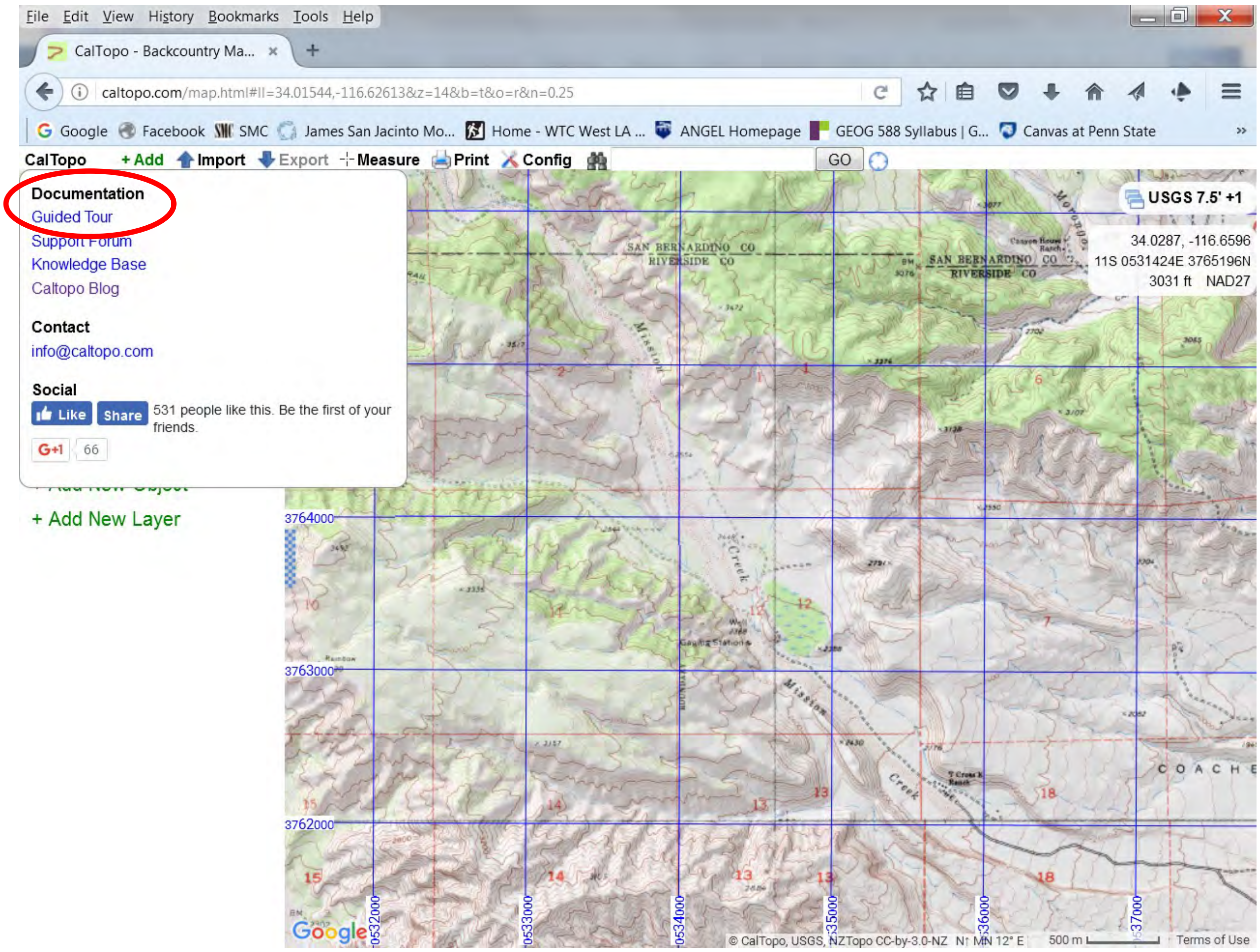
The sun moves 15◦ per hour. A finger width at arms length subtends about 1.5◦ to 2◦**,** which is about 6 to 8 minutes of time. Two four-finger hands on top of each other cover about 15◦.

The North Star or Polaris. Polaris lies roughly one half degree from the North Celestial Pole, so this particular star appears to remain stationary hour after hour and night after night. Between the Equator and the North Pole, the angle of Polaris above the horizon is a direct measure of latitude. "Latitude" is the angular distance north or south of the Earth's Equator. At the geographic North Pole (90° north latitude), Polaris is directly overhead at an angle of 90°. At the Equator (0° latitude), Polaris is sitting on the horizon with an angle of zero.



Look at the North Star and point one arm straight at it, and then hold your other arm level with the horizon. The angle between your arms is roughly the degrees of latitude of your location. Alternatively, if you know your latitude, you can use it to help locate Polaris in the night sky. In southern California, you will find Polaris to your north at 34° angle above the horizon. The Big Dipper is an excellent pointer toward Polaris.

CalTopo (http://www.caltopo.com). CalTopo is the go-to resource for hikers. For those unfamiliar with this resource, go to CalTopo's website and take a guided tour found under CalTopo on the menu bar (circled on the illustration). Unlike many web-based mapping programs, Cal Topo provides the option to select either the NAD27 or WGS84 datums. In addition, user-selected printing options enable printing at various map scales including the 7.5 minute scale. It also has a variety of layers to enrich the map such as UTM grid overlay (shown on the illustration), contour overlay, slope shading, and prior fire history.



GPS Apps. Any smartphone or device can be turned into a GPS device. There are many apps available both at the Apple Store and the Google Play Store. Some mapping applications are free and others require a fee.

SEAMLESSLY TAPING TWO MAPS TOGETHER

1. Fold under the right edge of the Sawmill Mt. map along the neatline (map margin) that forms the eastern edge of the map. On USGS maps, the neatline on the west and east margins is true north since it is a line of longitude; the neatlines on the top and bottom are lines of latitude.
2. Place the Sawmill Mt. map on the Cuddy Valley map and align its eastern neatline with the western neatline of the Cuddy Valley map. The contour lines on the two maps should line up without any white space showing.
3. Place tape over the seam of the two maps. Scotch Magic Tape (Matte Finish) works for this purpose. For best results, turn the map over and tape the seam on the back side.
4. When you are done, the map should look like the below image.

Note: Sometimes two maps are printed at slightly different scales, which makes it impossible to line up the contour lines of the two maps. If this is the case, line them up as best as possible.