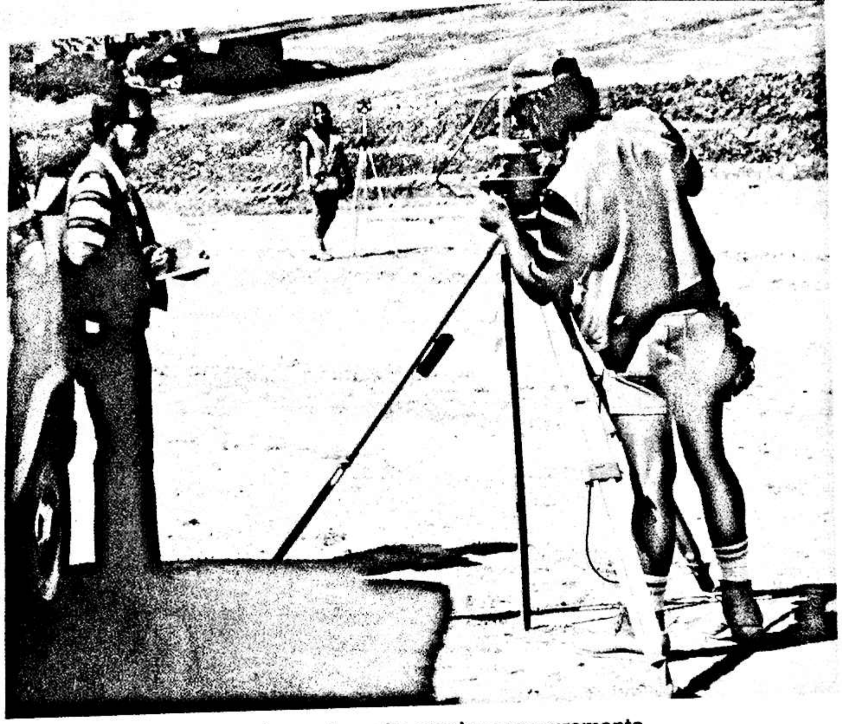


Land surveying teams use lasers to make precise measurements.

CHAPTER 5
Locating Positions on the Earth

You will know something about locating positions on the earth if you can:

1. Explain what is meant by a coordinate system and give examples of different types.
2. Name and describe the coordinate system used to find locations on the earth.
3. Describe the properties of regions of the earth in terms of fields.

Suppose you're on a ship in the middle of an ocean. How can you figure out where you are? How can you describe your location to someone else? In this age of travel, when the skies are filled with planes and the seas covered with ships, these questions are very important.

The system used to locate and describe positions on the earth must be a worldwide one used by all nations. And this is what we have. But before we learn about locating positions on the earth, we should learn something about the basic system used to describe locations on a flat surface.

COORDINATE SYSTEMS

Locating Points on a Flat Surface. Let's use a game to discover how the location of a point can be described so that anyone can find the point without question. On a piece of paper draw a square similar to the one in Figure 5-1. Place a point somewhere inside the square. How would you tell someone where the point is within the box?

If you measure the distance from the left-hand edge of the square to the point, you have one of the properties of the point. In Figure 5-1, the point is 2 cm from the left edge. Is this enough information to locate the point? Are there other points in the square that are 2 cm from the left edge? You're right if you see that many points could be at that distance—in fact, they would make another vertical line! So we need more information about the point to describe its location.

How far is the point from the bottom edge of the square? It is 3 cm up from the bottom. This distance is another property of the point. Now you have two measurements that you can use to describe the location of the point. Is this enough information to describe its location? Try giving someone the two measurements you've made for your point, and see if they can locate the same point on a drawing of their own.

Coordinate Systems. What you have just discovered is a basic fact about locating points on a surface. It takes two numbers to do it. Any system for assigning two numbers to every point on a surface is called a *coordinate system.* The system you have just used is a *rectangular coordinate system.* It makes use of two reference lines at right angles to each other. You locate a point by telling how far the point is from each line. One line is called the *horizontal axis;* the other, the *vertical axis.* The two numbers for a particular point are called its *coordinates.*

A coordinate system is often shown as a grid (see Figure 5-2). In this case the units of measurement are marked on the grid, and you just count them off to obtain the measurements for a given point.

Figure 5-1. Fixing the location of a point inside a square. The distances from two adjacent sides of the square are enough to fix the location of a point inside the square.

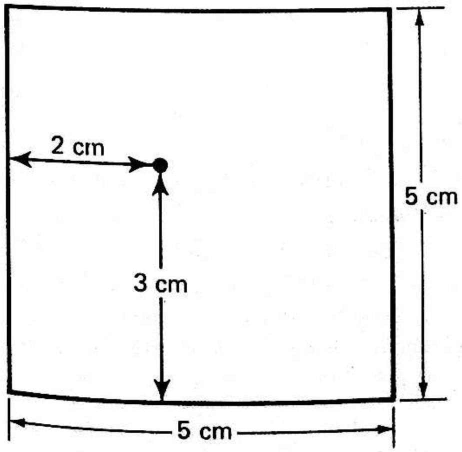
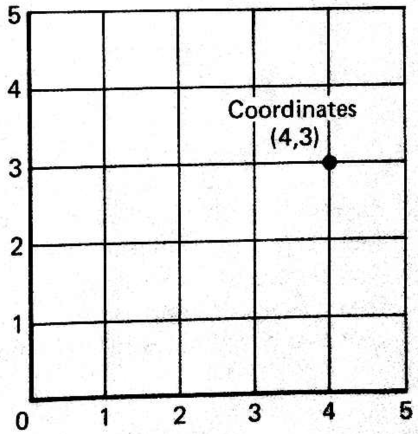


Figure 5-2. A grid for a rectangular coordinate system. The numbered grid lines help you find the coordinates of a point. A finer grid can be drawn to show fractions of units, such as fifths or tenths.



In Figure 5-2, the indicated point is 4 units from the vertical reference line and 3 units from the horizontal reference line. The *coordinates* for the point are (4, 3). (The numbers are always written in this order—the distance along the horizontal line first, the distance along the vertical line second.)

A rectangular coordinate system is a simple convenient one for flat surfaces. However, it is not the only possible coordinate system. For example, the two axes do not need to be at right angles. Figure 5-3 shows such a system. Another frequently used system has a central point as one reference and a line drawn from that point as the other reference. To find the coordinates of any point, you first draw a line to the reference point. The distance from the reference point to the given point is one coordinate. The angle between the connecting line and the reference line is the second coordinate. The distance and the angle together give a definite location for the point. This is called a *polar coordinate system*. Whatever the system, it always provides a different pair of coordinates for every point on the surface.

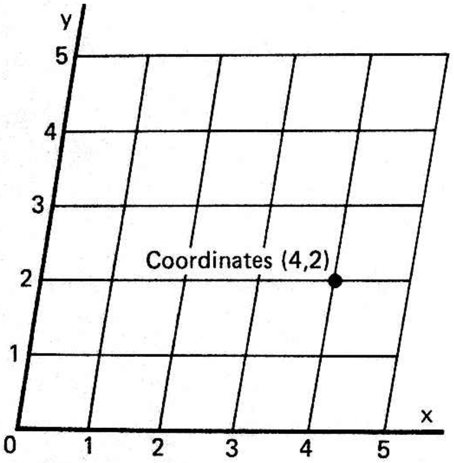


Figure 5-3. A coordinate system that is not rectangular. Distances to each axis are measured along lines that are parallel to the other axis.

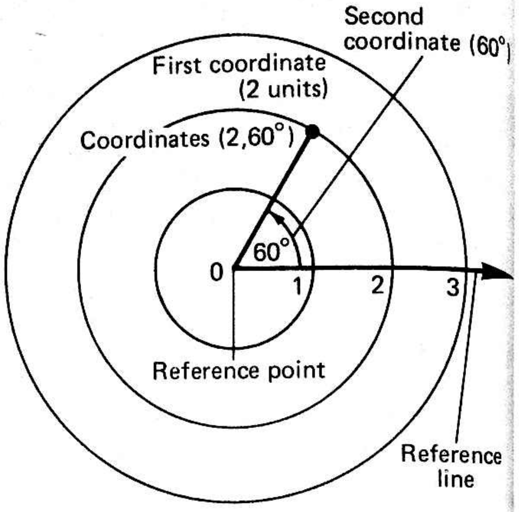


Figure 5-4. A polar coordinate system. In this system, one coordinate is a distance and the other is an angle.

SUMMARY

1. A coordinate system is a system of locating a point on a surface by means of two numbers, called the coordinates of the point.
2. Rectangular coordinates are a convenient system for a flat surface. The coordinates of a point are its distances from two reference lines that are at right angles to each other.
3. Other types of coordinate systems can be used for flat surfaces. They all give two coordinates for each point.

FINDING LATITUDE AND LONGITUDE

Locating Points on a Curved Surface. If we want to describe the location of a point on a curved surface, such as the surface of the earth, we have to invent a coordinate system to do it. Obviously, the system of rectangular coordinates that we used for a flat surface won't work on a sphere. We need a system of curved lines. The system that is generally used gives every point on the earth a pair of coordinates, called its *latitude* and *longitude*. Let's see how the system is set up.

The latitude-longitude system, by which we can locate any point on the earth's surface, consists of a grid of circular lines that covers the surface of the earth. There are east-west lines and north-south lines. So that you can see how this system was constructed, the first thing you should learn about are the reference lines for latitude and longitude.

The Equator and the Prime Meridian. The reference lines for the latitude-longitude system are the *equator* and the *prime meridian*.

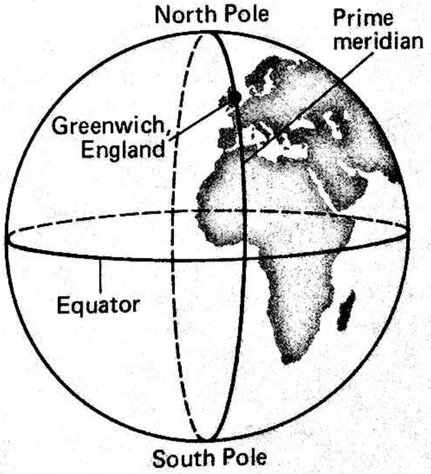
The equator is a line around the earth connecting all points midway between the North and South Poles (see Figure 5-5). The plane of the equator is at right angles to the earth's axis (an imaginary line running through the earth from pole to pole).

The second reference line for the system is the prime meridian. A meridian is a semicircle (half a circle) on the earth's surface that connects the North and South Poles. There are many different lines that do this. But the prime meridian is a reference line, and it has to be the same for everyone if the system is to be useful. The meridian passing through Greenwich, England, where the Royal Observatory was located, was the one chosen as the prime meridian.

Latitude. Latitude is a measurement of angular distance north or south of the equator. This angle can be measured along the arc of a meridian. An arc from the equator to either the North or South Pole is 90°. Thus, at the equator, latitude is 0°. At the North Pole, latitude is 90°N, and at the South Pole, latitude is 90°S. You must remember to specify north or south when giving latitude.

The parallels of latitude are east-west lines above and below the equator made by passing planes through the earth parallel to the plane

Figure 5-5. The two reference lines for locating points on the earth by latitude and longitude.



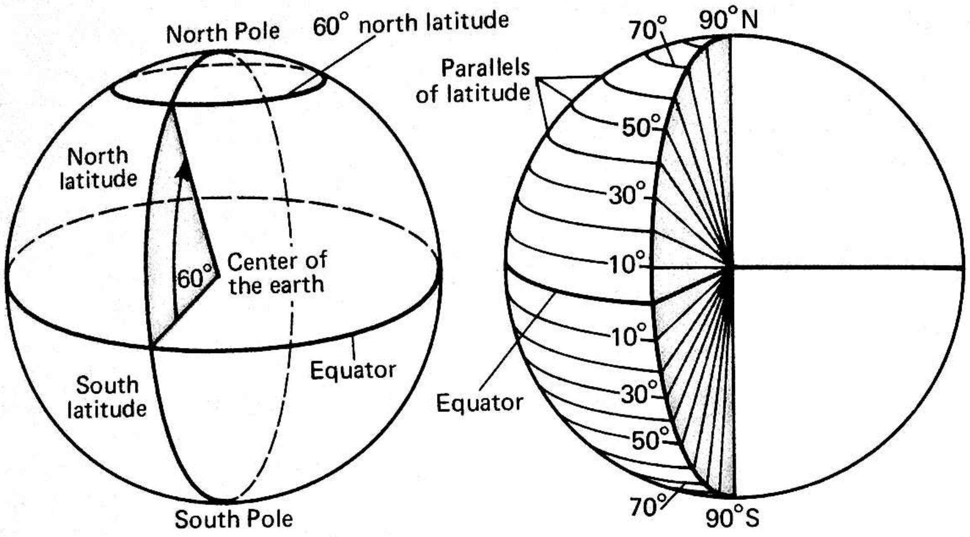


Figure 5-6. Parallels of latitude. The latitude of a point on the earth is its angular distance north or south of the equator, measured from the center of the earth. Points with the same latitude are on a circle parallel to the equator.

of the equator. The resulting circles are all parallel to the equator and parallel to one another, and they are all smaller than the equator (see Figure 5-6). The latitude is the same everywhere along a given parallel.

Measuring Latitude. In the Northern Hemisphere, latitude can be measured by measuring the altitude of Polaris. The latitude reading of a given location is equal to the altitude of Polaris at that location. For anyone at the equator, the altitude of Polaris is 0°. Thus latitude at the equator is 0°. At the North Pole the altitude of Polaris is 90°. Latitude at the North Pole is 90°N. If you are at a latitude of 45°N, the altitude of Polaris (the angle between the horizon and Polaris) will be 45°. If the altitude of Polaris is 37° at a certain location, the latitude of that location is 37°N.

Polaris cannot be seen in the Southern Hemisphere. So below the equator the altitudes of other stars are used to find latitude. In either hemisphere, if a very precise measurement of latitude is needed, then both the date and the time must be taken into account. There are astronomical tables that can be used to make such a calculation.

Longitude. Longitude is a measurement of angular distance east or west of the prime meridian. The *meridians of longitude,* like the prime meridian, are semicircles on the earth's surface connecting the North and South Poles. The longitude of the prime meridian is 0°. The meridian that is a continuation of the prime meridian has a longitude of 180°. Going east or west from the prime meridian, longitude increases up to 180°. Just as you must specify north or south with latitude, you must specify east or west with longitude.

The longitude of any given point on the earth's surface is the number of degrees (the angle) between the prime meridian and the meridian passing through that point. The angle is usually measured along the equator, but it can be measured along any of the parallels of latitude.

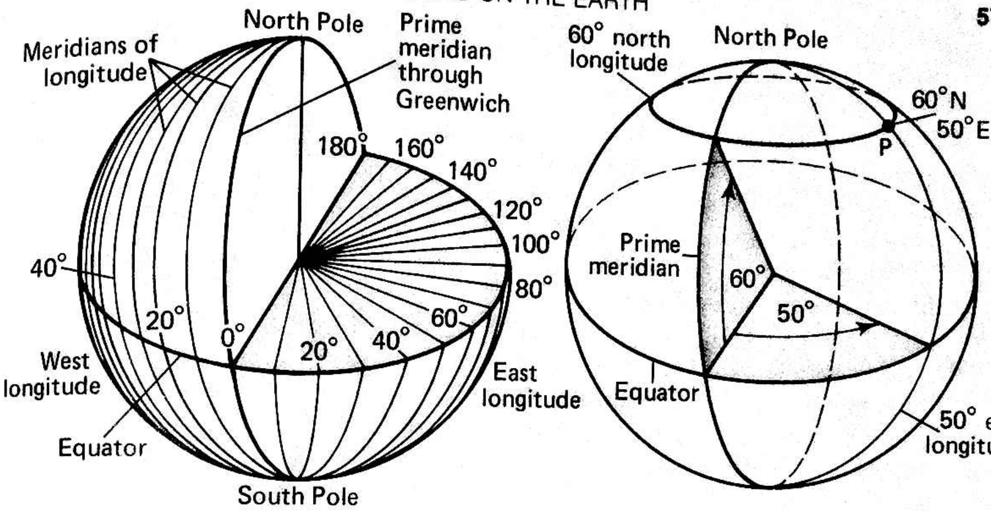


Figure 5-7. Longitude. The longitude of a point on the earth is the angular distance of its meridian east or west of the prime meridian, measured along the equator. Latitude and longitude are the two coordinates that fix the location of a point on the earth's surface. For example, only one point has a latitude of 60°N and a longitude of 50°E.

Measuring Longitude. High noon, the time at which the sun is at its highest point in the sky, occurs at the same time for all locations along a single meridian. The difference in time between high noon at any given point (local noon) and high noon at the prime meridian is the basis for measuring longitude.

The sun appears to move around the earth from east to west once every 24 hours. A complete circle has 360°. If you divide 360° by 24 hours, you find that the sun appears to move at the rate of 15° per hour. This means that if your longitude is 15° west of the prime meridian, your local noon will occur 1 hour later than noon at the prime meridian. It takes the sun 1 hour to move from the prime meridian to your meridian. In general, local noon occurs 1 hour later for each shift of 15° longitude to the west.

You can calculate longitude by finding the time difference between your local noon and noon at the prime meridian in Greenwich, England. If your local noon occurs before noon at the Greenwich meridian, then your longitude is east of the prime meridian. If your local noon occurs after noon at the Greenwich meridian, then your longitude is west of the prime meridian.

To find longitude, you must know what time it is in Greenwich, England, when it is noon where you are. This can be done either by having a clock that is set for Greenwich Time or by listening to radio signals that regularly give this information. If your local noon occurs at 5 P.M. Greenwich Time, then 5 hours have passed since noon at the prime meridian. During that 5 hours the earth will have rotated 5 x 15°, or 75°. Thus, your longitude is 75°W. If your local noon occurs at 11 A.M. Greenwich Time, your longitude is 15°E.

SUMMARY

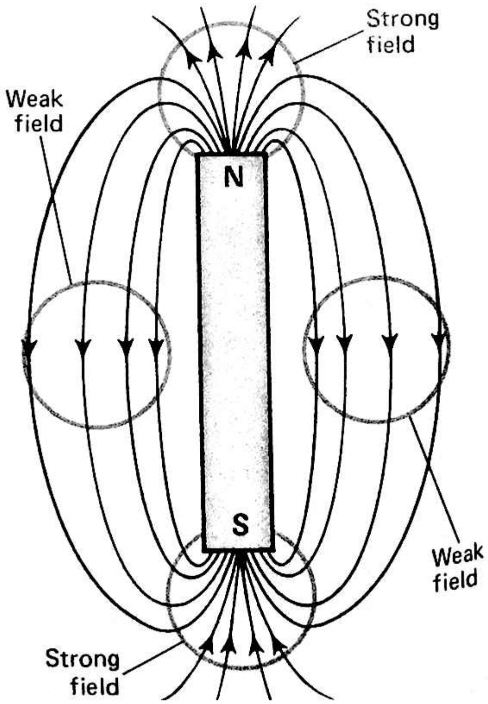
1. The latitude-longitude system is a coordinate system using two sets of lines that make a grid covering the earth's surface.
2. The latitude and longitude of an observer can be determined by means of celestial observations.
3. The east-west lines are the parallels of latitude. The north-south lines are the meridians of longitude.
4. Latitude is a measurement of angular distance north or south of the equator.
5. Latitude in the Northern Hemisphere can be found by measuring the altitude of Polaris. For any location in the Northern Hemisphere, latitude is equal to the altitude of Polaris at that location.
6. Longitude is a measurement of angular distance east or west of the prime meridian.
7. To find longitude you must know the time difference between local noon and noon at the prime meridian.

DESCRIBING EARTH FIELDS

We already know something about the size and shape of the earth and how to locate our position on the earth. We are now ready to find some ways to describe other physical characteristics of our earth environment.

Fields. A field is a region of space in which there is a measurable quantity of a given property at every point. Magnetism is a good example of a field quantity. As you recall, objects made of iron or steel are attracted toward a magnet, and the force of attraction becomes stronger as the object approaches the magnet. We say there is a *magnetic field* in the space around the magnet. The strength of that field varies from point to point, depending on the distance from the magnet's poles. The earth has a gravity field around it. Objects are attracted toward the earth with varying force, depending on their distance from the earth's surface.

Figure 5-8. The magnetic field around a bar magnet. The field lines show the direction of the magnetic force. The closeness of the spacing of the lines indicates the strength of the magnetic force. This is a vector field, because the field quantity has both magnitude and direction.



There are other kinds of measurable quantities that vary from place to place on or near the earth's surface. Each of these makes up a different kind of field. Among these measurable field quantities are atmospheric pressure, wind velocity, and temperature. The elevation of the earth's surface above or below sea level can also be thought of as a field, since there is a definite measurable elevation at each point of the surface.

Vector and Scalar Fields. Some types of fields can be completely described in terms of amount, or *magnitude*. Fields of this type are called *scalar fields*. Temperature, relative humidity, and atmospheric pressure are scalar fields. They can be completely described in terms of their size, or magnitude, alone.

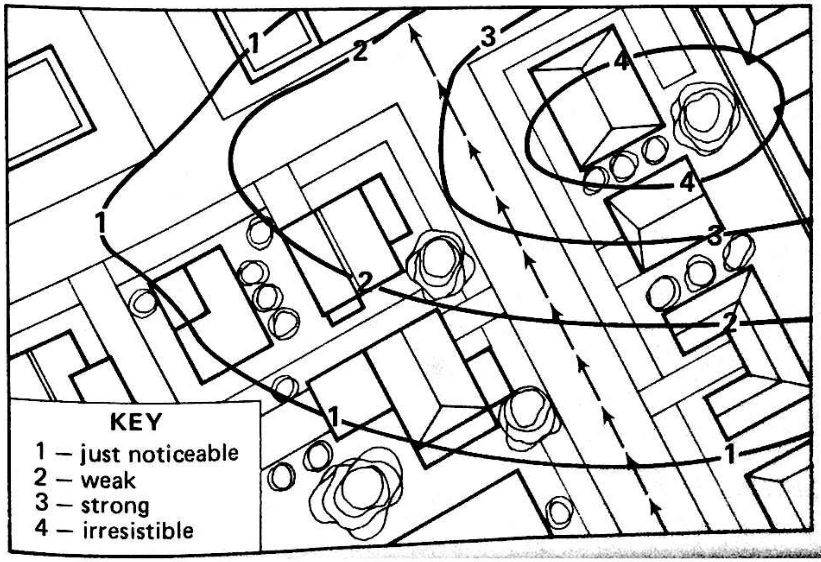
Other types of fields cannot be described simply in terms of magnitude. Such fields need both magnitude and *direction*. Fields of this type are called *vector fields*. Wind velocity, gravity, and magnetism are examples of vector fields. A description of the wind must include not only the magnitude of its speed, but also the direction it's coming from. A problem that involves the force of gravity must also take into account the direction of this force.

Field Maps. When you are studying a particular field, it is often helpful to make a map of the region involved. On the map you can mark the various readings obtained for the property being studied.

Suppose you are walking down the street and suddenly notice the odor of barbecuing hamburgers. You have just entered a field. Farther down the street the smell becomes stronger, but by the time you reach the corner, the smell is weak again. If you take a shortcut through some backyards and go back toward the middle of the block, the smell becomes stronger and stronger. Eventually you may reach the source of the odor. If you're lucky, you'll be invited to help eliminate the cause of this field!

Figure 5-9 is a map showing part of the odor field from barbecuing ham-

Figure 5-9. Map of the odor field of a hamburger barbecue. The irregular shape of the field is probably due to winds or air currents. Which way do you think the wind is blowing?



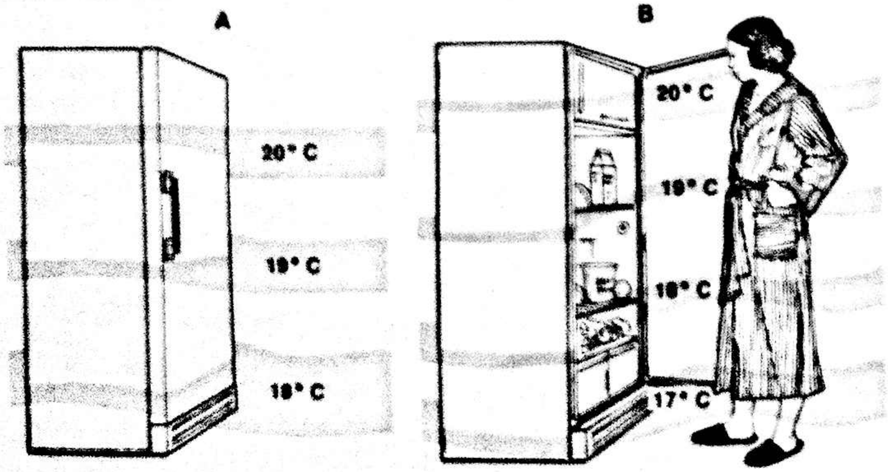
burgers. The map key gives the meanings of the numbers used on the map. From the information on the map, can you tell where you would have the best chance of finding the hamburgers?

Isolines. On the map in Figure 5-9 you will notice that there are lines connecting all points having the same field value. These are *isolines*. Isolines connect points of equal value on field maps. Putting in isolines on a field map can give you a good idea of the shape of the field and the pattern of change within the field. For example, on weather maps all points showing the same temperature are connected by isolines. These isolines are called *isotherms*. They give you a clear picture of the temperature pattern within the map area.

Isosurfaces. Isolines show field conditions on a two-dimensional surface. For example, isotherms on a weather map generally show temperatures within the map area at ground level. But you can't tell from such a map what is happening at various levels above the ground. To get a three-dimensional picture of conditions within a field area, you must use isosurfaces. An *isosurface* is a surface (rather than a line) that passes through all points with the same field value.

Figure 5-10 is a model of the three-dimensional temperature field in a room with a refrigerator. In A, the isosurfaces show the temperature pattern around the refrigerator when its door is closed. Because warm air rises, the air is usually warmer near the ceiling of a room than near the floor. Therefore, the higher isosurfaces represent points in the field at higher temperature. With the refrigerator door closed, the isosurfaces are fairly flat, but with a dip near the floor where heat is being given off. (A refrigerator keeps its interior cold by "pumping" heat to the outside.)

Figure 5-10. An example of isosurfaces in a model of a three-dimensional field. Each gray surface in the model shows points that have the temperature marked on the surface. When cold air flows out of the refrigerator, temperatures drop, causing each isosurface to bend upward.



When the door is opened (B), cold air flows out of the refrigerator toward the floor. This causes the isosurfaces to bulge upward over the cold air.

Field Gradients. As we move from one point to another in a field, we usually find that the field quantity changes. The rate at which a field quantity changes as we go from one point in the field to another is called the *gradient*, or *slope*, of the field between these two points. The average gradient of a field over a given distance can be calculated from the formula below.

If the field quantity shows a large change in a short distance, the gradient is large, or steep. If the change is small over a fairly large distance, the gradient is small, or gradual.

An example of the calculation of a field gradient will be given in the discussion of contour maps on the following pages.

Time Changes in Fields. Field gradients usually apply to changes in fields when space is the frame of reference. It is assumed that the field as a whole is not changing with time. However, most properties of the environment do change in the course of time. Therefore, a field map may be accurate only for the time at which it was made. An example of an earth field that slowly changes with time is the earth's magnetic field. The elevation field is also changing on most of the earth's land surfaces.

$$\text{Gradient} = \frac{\text{Amount of change in the field quantity}}{\text{Distance over which the change occurs}}$$

SUMMARY

1. A field is a region of space that has a measurable value of a given property at every point.
2. Scalar fields can be completely described in terms of magnitude.
3. Vector fields can be described in terms of magnitude and direction.
4. Isolines are lines on a field map connecting all points of equal value. They show field values on a two-dimensional surface.
5. An isosurface is a surface passing through all points of equal field value within a three-dimensional region of space. Isosurfaces show how the field varies both horizontally and vertically within the mapped region.
6. The gradient of a field is the rate at which field quantities change from place to place.
7. Field characteristics generally change with time.

CONTOUR MAPS

A *contour map*, or *topographic map*, is a map on which elevations of the surface are shown by means of isolines called *contour lines*. Each contour line passes through points that have the same elevation. The contour lines are drawn for a fixed difference of elevation, such as every 10, 20, or 50 feet. This difference between adjacent contour lines is called the *contour interval* of the map.

Figure 5-11 shows a drawing of a portion of the earth's surface that includes hills, valleys, streams, and a seashore. Below the drawing there is a contour map for the same region. To help you understand what a contour line means, the 200-foot contour is shown on the drawing. Imagine that all the land above the 200-foot level had been sliced off and that you were looking down on the top surface that was left. The 200-foot contour line on the map is the outline of the flat surface you would see. Similarly, each of the other contour lines is the outline of what you would see if the land were sliced off above that line.

Notice how the contour lines are bunched together along the steep sides of the cliffs, while they are widely spaced along the gentle slopes on the top of the cliffs. Another characteristic of contour lines is the way they bend when crossing streams or valleys. They always point upstream or toward higher elevations.

Topographic maps often contain symbols for or special ways of indicating various natural or manmade features of the surface, such as swamps, bodies of water, roads, and buildings. The meaning of these symbols may be shown in a map *key*. Maps usually have a *scale* of distance. The scale tells you the relationship between a distance as measured on the map and the actual distance on the earth's surface. The scale is usually a line marked off in distance units, such as feet, kilometers, or miles. The map scale may also be shown as a ratio, such as 1 cm = 2 km. This means, for example, that two points that are 3.5 cm apart on the map are actually 7.0 km apart.

Maps almost always include an arrow indicating north. Maps are usually drawn with north at the top, but this is not always the case. If you are using a map to find the direction from one point to another, look first for the north arrow to be sure which way is north on the map.

Elevation Gradients. The earth scientist is a detective. He tries to reconstruct the past, that is, to figure out what happened to make the earth's surface what it is today. He also tries to predict future changes that are likely to occur. One of the chief forces that change the shape of the land is running water. The power of running water to change the land depends partly on its speed, and its speed depends on the steepness or gradient of its course. Thus the gradient of a particular region is often an important clue for the earth detective.

We have already seen how the contour lines on a topographic map indicate steepness in a general way. Where they are close together, the elevation changes rapidly over a short distance; that is, the surface has a steep gradient. Where they are widely spaced, the gradient is gradual. But a topographic map can give us more precise information about the rate of change of elevation. By using the map scale and the contour interval, we can calculate a numerical value for the gradient of the surface.

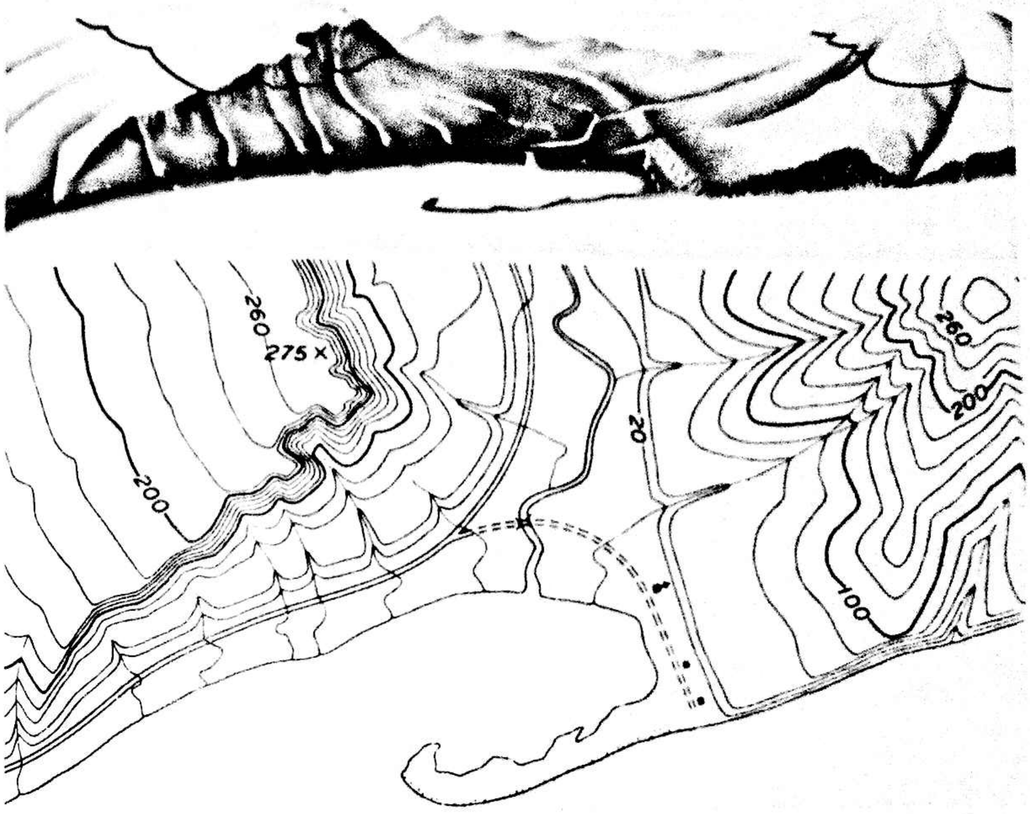


Figure 5-11. A portion of the earth's surface and its representation by a contour map. The contour lines for hundred-foot elevations are numbered and drawn heavier for greater ease in reading the map. Since there are five contour intervals for every 100 feet, we can see that the contour interval is 20 feet.

As an example, let us find the average gradient between points *A* and *B* on the map in Figure 5-12. The contour interval is 20 feet. We see that the elevation from *A* to *B* changes from 140 feet to 20 feet, a difference of 120 feet. Using the map scale, we find that the distance from *A* to *B* is 2 miles. The gradient is then:

$$\frac{\text{120 feet}}{\text{2 miles}} = \text{60 feet/mile}$$

Profiles. Another important clue for the earth scientist is often the shape of the land between two points. By this we mean the shape we would see if the land were sliced vertically along the line between the two points. This shape is called a *profile*. A profile is actually a graph of elevation against distance along a line. A profile can be drawn quite accurately using the information on a topographic map.

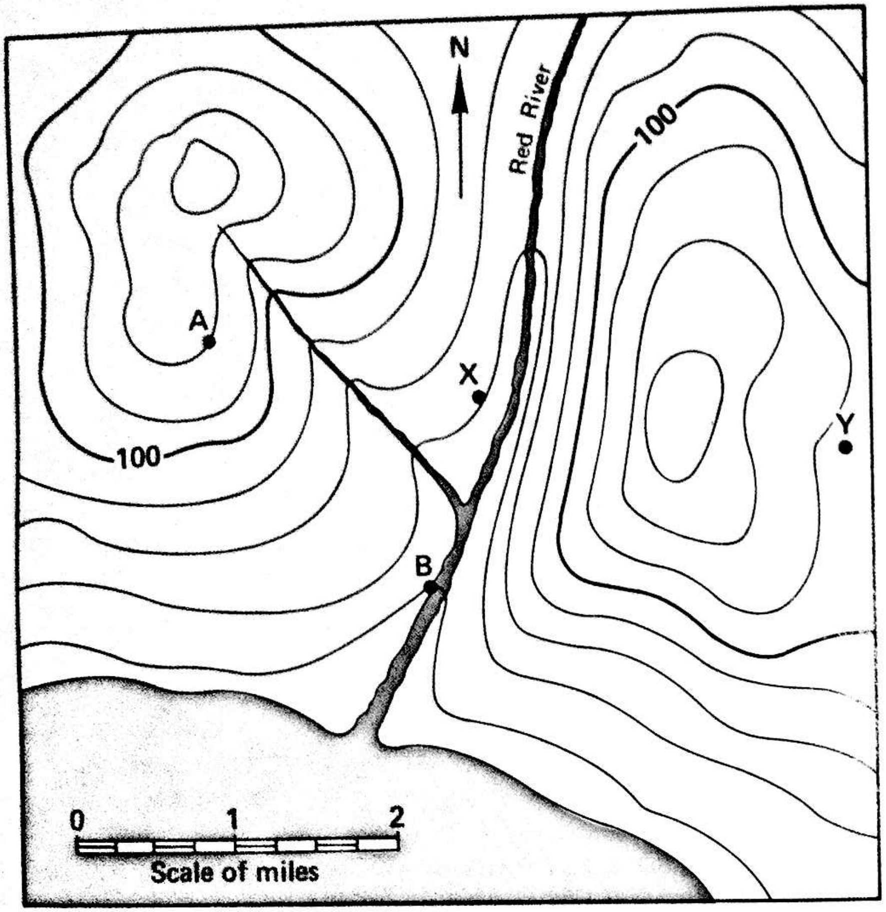


Figure 5-12. A contour map.

As an example, let us construct a profile between points *X* and *Y* on the map in Figure 5-12. The line from *X* to *Y* will be the horizontal axis of our profile graph. The vertical scale of the graph will have to include elevations up to the maximum that the line crosses, which is between 180 and 200 feet. In Figure 5-13A we see the axes of the graph ready for use.

Now we lay the edge of a card along the *X-Y* line on the map, and we mark the edge of the card wherever it crosses a contour line. We also label the marks with the elevation of the corresponding contour line. This is illustrated in Figure 5-13B.

The next step is to copy the marks from the card on to the horizontal axis of the graph, as in Figure 5-13C. This process puts the marks on the graph axis the same distance apart as the points where the *X-Y* line crosses the contour lines on the map.

We now draw a line vertically upward from each point on the axis to the elevation corresponding to that contour line. Finally, we draw a smooth curve connecting the tops of the vertical lines (see Figure 5-13D). This is the profile of the surface between *X* and *Y*.

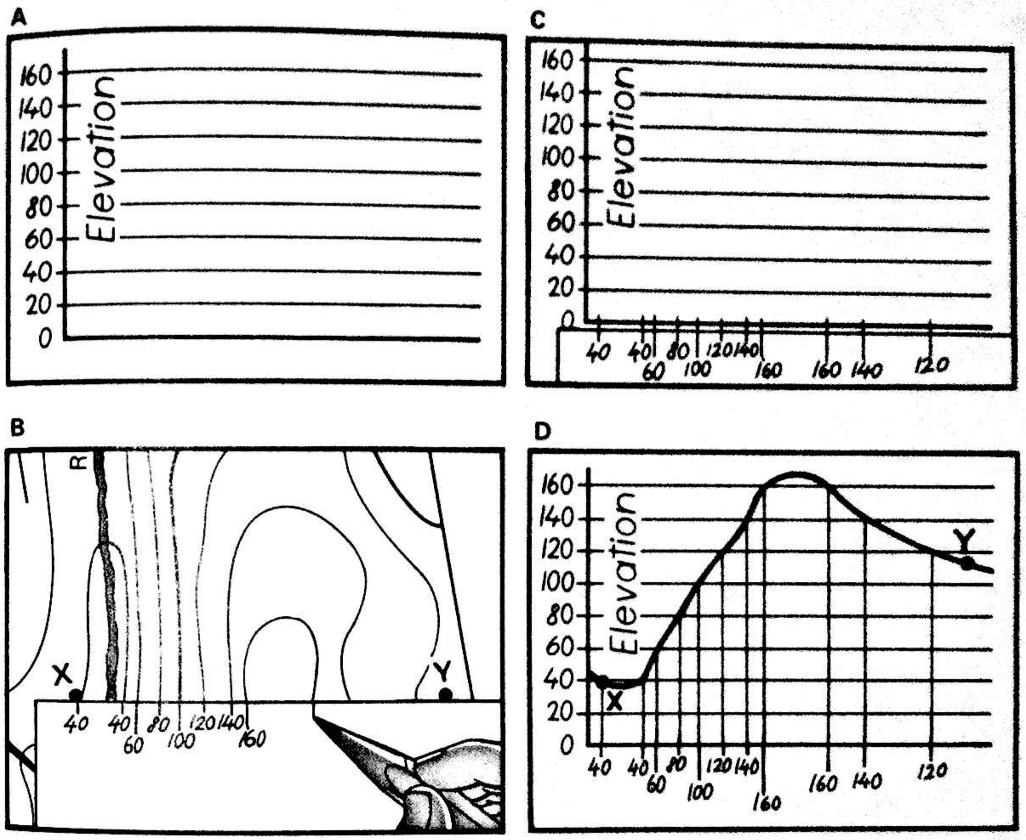


Figure 5-13. Constructing a profile between points *X* and *Y* on the map in Figure 5-12.

SUMMARY

1. A contour map is a map showing the elevation field of a portion of the earth's surface.
2. The contour lines on a contour map pass through points that have the same elevation.
3. Where contour lines are closely spaced, the gradient, or slope, of the surface is steep. Where contour lines are widely spaced, the gradient or slope is gradual.
4. A profile, or vertical section, of the surface along any chosen line can be constructed from the information in a contour map.

REVIEW QUESTIONS

Group A

1. What is a coordinate system?
2. What type of coordinate system is convenient for flat surfaces?
3. How many coordinates are necessary to locate a point on a surface?
4. What system of coordinates is used to locate positions on the earth's surface?
5. What are the reference lines of the latitude-longitude system?
6. What is latitude and how is it found?
7. What is longitude and how is it found?
8. What is a *field?*
9. How can you describe a *scalar* field?
10. How can you describe a *vector* field?
11. What is an *isoline?*
12. What is an *isosurface?*
13. What is a *field gradient?*

Group B

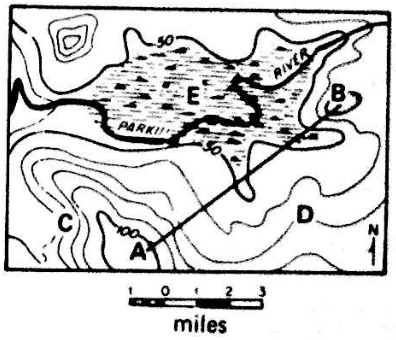
1. a. What basic parts are common to all coordinate systems?
   b. We use coordinate systems in many ways during our everyday experiences. Some of these experiences are locating streets and houses in cities, locating places on road maps, constructing mathematical graphs. Explain how each of these makes use of a coordinate system. Can you think of other examples?
2. Suppose you are planning to make a long trip. What changes could you expect to observe because your latitude changes? Because your longitude changes?
3. a. Three common fields that we are familiar with are gravitational, magnetic, and temperature. List three fields used in weather reporting and three fields used in pollution reporting.
   b. What kinds of information are available on a contour map that are not available on a standard road map?

REVIEW EXERCISES

1. In calculating the circumference of the earth, Eratosthenes made two assumptions—first, that the earth was round, and second, that the sun was very far away. But what if these assumptions had been wrong? Let's assume that the earth is flat. Can you figure out how near the earth the sun would have to be for the sun to be directly overhead at Syene but 7½° from the vertical at Alexandria?

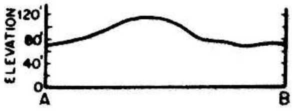
   To begin with, you'll need a piece of graph paper, a protractor, and a ruler. With these instruments you can draw a scale model and measure off the distance to the sun. Start by choosing the scale you're going to use. We know that the distance from Syene to Alexandria was assumed to be 5,000 stadia. So pick a length on your graph paper to represent this distance. Next put in the sun's rays at both locations. At Syene the sun was directly overhead, so draw a vertical (90°) line from that point. At Alexandria the sun's rays were at an angle of 7½°. Mark off the angle with the protractor, and draw in the line representing the sun's rays at Alexandria. Where the two lines representing the sun's rays meet, would be the sun. How far would the sun have to be from the earth to satisfy members of the Flat Earth Society?

2. List three examples of physical models not mentioned in the text. List three examples of mechanical models not mentioned in the text.
3. Give an example of the use of scale in making models. Find a model of something and identify the type of model it is. Describe the accuracy of the scale of the model to the real object. Use actual measurements if possible.
4. Suppose you are on a ship somewhere in the Atlantic Ocean. You take sightings on Polaris and find that its altitude is 48°. You're told that a certain star is on the prime meridian at midnight Greenwich time. This star is on your meridian at 3 A.M. G.M.T. What is your latitude and longitude?
5. Base your answers to the following questions on the diagram below.

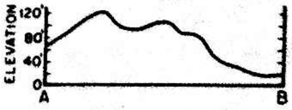


   a. What is the contour interval of the map?
   b. From which direction does the river in the map flow?
   c. Which of the four diagrams below best represents the profile view along line *AB?*

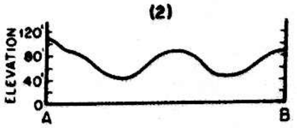
(1)



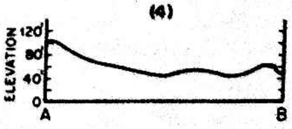
(3)



(2)



(4)



   d. What is the straight-line distance in miles from *A* to *B?*
   e. What is the greatest possible elevation of point *B?* What is the lowest possible elevation of point *B?*
   f. What is the approximate gradient in feet/mile at points *C, D,* and *E?*