CHAPTER 3

THE LAY OF THE LAND: THE TOPOGRAPHY OF THE EARTH'S SURFACE

1. LATITUDE AND LONGITUDE

1.1 You probably know already that the basic coordinate system that's used to describe the position of a point on the Earth's surface is *latitude and longitude*. In this system (Figure 3-1), the Earth is imagined to be cut by a series of planes that pass through the north–south axis of rotation. The intersection of such a plane with the Earth's surface is called a line (really a curve) of **longitude**, or a **meridian**. Longitude is measured in degrees, from zero to 360. One meridian (the one that passes through Greenwich, England) is called the **prime meridian**, and longitude is measured 180 degrees to the west of that and 180 degrees to the east of that. The opposite meridian, 180 degrees around the world from the prime meridian (and the intersection of the longitude plane with the other side of the world) lies about in the middle of the Pacific Ocean.

1.2 One consequence of this definition of longitude is that *the spacing between two meridians gets smaller as you go north or south from the equator*. Think about this the next time you fly west in a jetliner: You would have to move awfully fast to keep up with the sun, and land at the same time of day you took off, if you're flying along the equator, but if you're flying east to west in the far north or far south on the earth, you could easily arrive at your destination a lot earlier in the day than you took off!

1.3 The other element of the coordinate system is a series of latitude circles (Figure 3-1). These **latitude circles** are *small circles that are perpendicular to the earth's north-south axis*. (A **small circle** is *the intersection between the surface of a sphere and a plane that cut through the sphere but does not pass through the center of the sphere*. That's in contrast to a **great circle**, which is formed by *the intersection between the surface of a sphere and a plane that cuts through the sphere and passes through the center of the sphere*.) These small circles are formed by passing planes parallel to the equatorial plane through the earth. By convention, the **equator** (*the curve on the earth's surface that's formed by passing a plane through the center of the earth and perpendicular to the north–south axis*) is at zero degrees latitude, and the north pole and south pole are at 90° latitude.

1.4 Big maps of the earth's surface that are bounded by latitude and longitude lines (as most maps are) are *not rectangular*: they narrow to the north in the northern hemisphere, and they narrow to the south in the southern hemisphere. Maps of smaller areas, of the kind geologists use when

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they are mapping in an area that's a small part of a state, are so close to being rectangular that one can usually ignore the effect of narrowing of longitude lines.
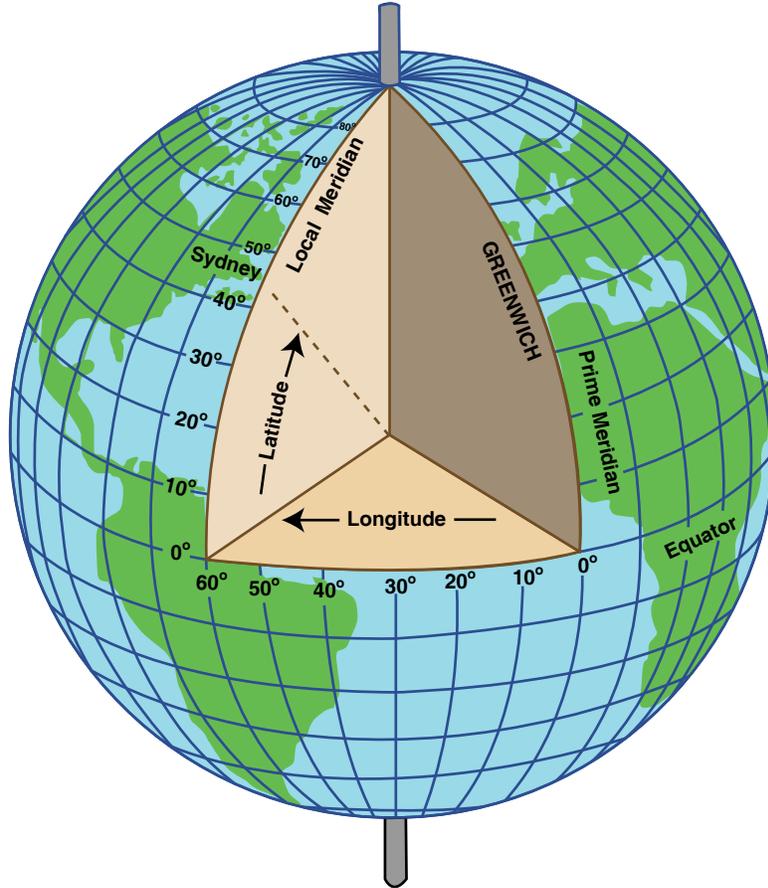
Figure 3-1. Latitude and longitude. (From Greenhood, 1964.)

2. MAPS

2.1 Earth science is a very map-oriented discipline, because geologists are always having to view and think about the disposition of rock bodies across the landscape. This section provides just a little elementary material about maps. ***Cartography***, a well developed discipline in its own right, is *the study of maps as maps*.

2.2 People have been drawing maps to show the relative disposition of things on the earth's surface for a very long time. The accuracy of maps has

improved as the ability to locate things relative to one another (which in one way or another always involves what could be termed *surveying*) has improved.

2.3 One unavoidably troublesome aspect of map-making has been (and continues to be) the need to transform spatial relationships on the surface of a nearly spherical body, the earth, into spatial relationships on a flat piece of paper, the map (Figure 3-2). The only way around this problem is to *draw the map on a small globe*, but the obvious impracticality of carrying around and using a globe-shaped map make that expedient not very useful. Various kinds of **projections**, or *ways of systematically distorting a segment of a spherical surface to make it fit onto a plane*, have come into use. Each such kind of projection has its advantages and disadvantages. For geologic maps of fairly small areas you don't need to worry about the problem of projections, but for maps of whole countries and continents, or even of the states of the U.S., you do.
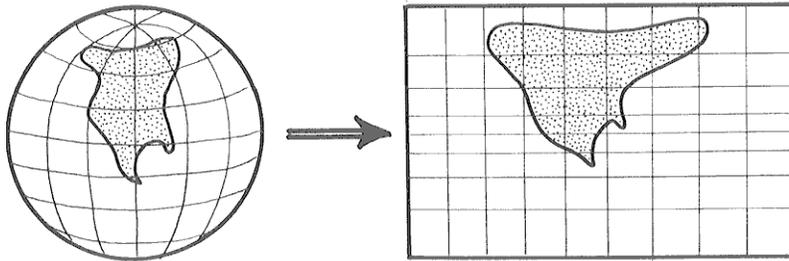

Figure 3-2. Trying to transform an area on a sphere into an area on a plane.

2.4 Aside from the fundamental requirement of representing accurately the spatial relationships in accordance with a given kind of projection, there are just a few elements essential to all maps:

- A *scale*, which expresses the ratio of a given horizontal distance on the map to that same horizontal distance on the actual land surface. This can be expressed as a numerical ratio, or it can be drawn as a labeled scale bar on the map, or (preferably) both.

- A *north arrow*, an arrow somewhere on the map, usually in the margin, that shows the direction of true north.

- A *key* or *legend* that explains to the user of the map all of the various symbols that show features on the map.

3. MAP SCALES

3.1 All maps have to have a scale. The **scale** of a map is *the ratio of the distance between any two points on the map and the actual distance between the corresponding points on the Earth's surface*. It's usually expressed as a ratio, called the **representative fraction**, one divided by some number, like 1:25,000 or 1/25,000. It can also be expressed as a *verbal statement*: for example, one inch equals one mile, or one centimeter equals one kilometer. Most maps also show the scale graphically, by having a *horizontal bar at the bottom of the map with tick marks along the bar* labeled with the distances represented by the positions of the tick marks along the bar.

3.2 Here's something really tricky to remember about maps scales:

> A **large-scale map** is one that uses a relatively *large* distance on the map to represent a given distance on the Earth's surface

> A **small-scale map** is one that uses a relatively *small* distance on the map to represent a given distance on the Earth's surface.

This is confusing, because *a small-scale map tends to cover a relatively large area of the earth's surface*, and *a large-scale map tends to cover a relatively small area of the earth's surface*!

4. TOPOGRAPHIC MAPS

4.1 Almost all of the area of the United States has been represented on topographic maps at various scales. For many years there were two standard map scales:

> Maps, called fifteen-minute quadrangle maps, that spanned 15' of longitude and 15' of latitude at a scale of 1:62,500, which is exactly one inch to the mile.

> Maps, called seven-and-a-half-minute quadrangle maps, that spanned 7-1/2' of longitude and 7-1/2' of latitude at a scale of 1:24,00.

4.2 In recent times those quadrangle maps have been supplanted by seven-and-a-half-minute quadrangle maps that are about the same size at the old 1:24,000 maps but at a slightly different, but more rational scale of 1:25,000. In addition, there is a series of maps with a scale of 1:250,000, called *quarter-million maps*. These latter, newer, maps use the metric system

for map distances and contour intervals.

4.3 The 1:25,000 maps are what geologists typically use as a base for mapping the geology of a local area. The resulting maps are called ***geologic quadrangle maps***. But often the detail of mapping that the geologist desires calls for a larger scale: that is, the map scale is such that a smaller land area is represented on a given sheet of paper. Detailed geologic maps are often at scales of between 1:10,000 and 1:5,000. *The scale of map you work with depends on the level of detail you want to show on the map.*

5. TOPOGRAPHIC CONTOURS

5.1 Many maps of land areas have series of curved lines, called contours, that represent the topography of the area. Such a map is called a ***topographic map***. A ***contour*** is *a horizontal curve that's the locus of all points on the map with the same elevation* (Figure 3-3). A good way to understand the concept of contours is to choose a series of elevations and imagine passing a corresponding series of horizontal planes through the landscape (Figure 3-4). The contours are formed by the intersection of these planes with the land surface.
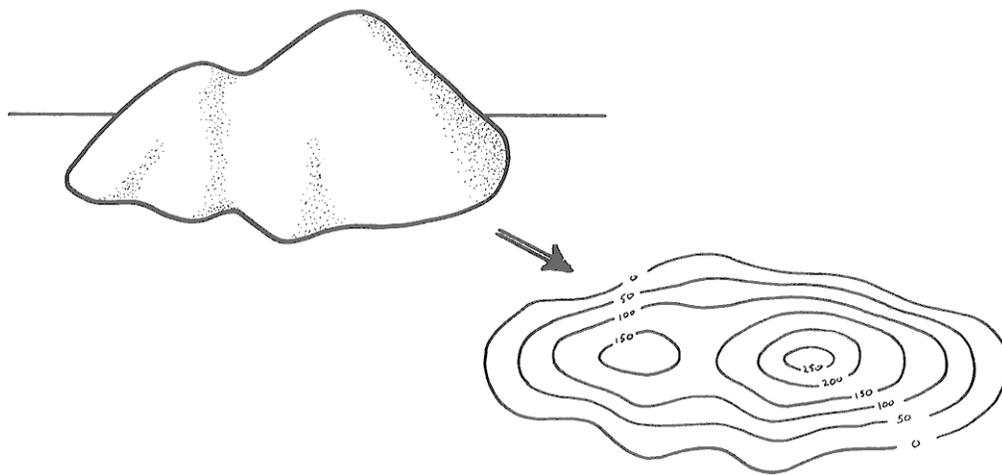

Figure 3-3. Topographic contour lines.

5.2 Adjacent contours touch one another only where the land surface is vertical, and they cross one another only where one part of the land surface hangs over another part (and in such overhanging areas, by convention the

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contours are dashed or dotted to indicate the overhanging relationship, or just omitted altogether).
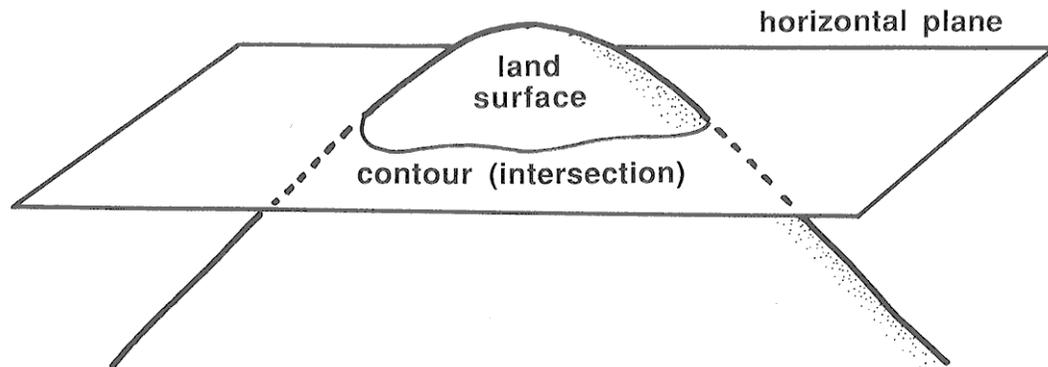

Figure 3-4. Viewing contours as the loci of horizontal planes with the land surface.

5.3 Topographic maps are useful to both technical people (geologists; environmental engineers) and to everyday people, like hikers. A geologist often uses a topographic map as a base on which to plot geology in making a geologic map.

6. INTERPRETING CONTOUR LINES ON TOPOGRAPHIC MAPS

6.1 To be a sophisticated user of a topographic map, you have to be able to *visualize the topography or "lay of the land" by examining the contour lines.* Or, even if you can't do a good job of visualizing the topography, you at least have to understand how to interpret it from the contour lines. Here are some basic pointers. The best way to learn how to visualize topography from contour lines is to practice with a real map—and you will be doing that in the take-home exercise.

6.2 For a map at a given scale, *the more closely spaced the contour lines, the steeper to slope of the surface*: closely spaced contour lines mean steep slopes, and widely spaced contour lines mean gentle slopes (Figure 3-5).

6.3 You can easily compute the local slope of the land surface, by:

(1) measuring the distance between two points on the map,

(2) using the map scale to find the real distance on the land surface,

(3) finding the difference in elevation between the two points from the contour lines (at each point you usually have to interpolating between adjacent contour lines),

(4) forming a right triangle with one leg the horizontal distance and one leg the vertical distance, and
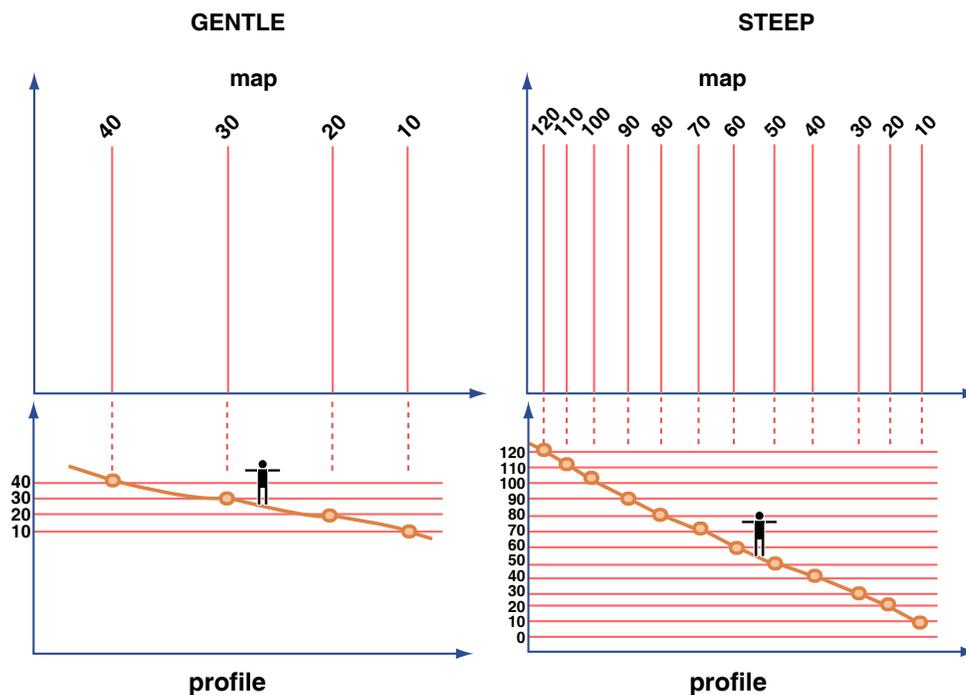
(5) finding the slope angle by trigonometry.

Figure by MIT OCW

Figure 3-5. Contours on gently sloping surfaces vs. contours on steeply sloping surfaces.

6.4 I suppose I need not insult your intelligence by pointing out (Figure 3-6) that hills or ridges are located where the contour lines on either side of the hill or ridge increase in elevation toward the top of the hill, and valleys are located where the contour lines on either side of the valley decrease in elevation toward the bottom of the valley.

6.5 Valleys usually slope in one direction or another because they are occupied by streams, which, as you know, flow downhill. Such a valley

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shows up on the topographic map as a series of V-shaped kinks in the successive contour lines. Those "V"s point *up* the valley (Figure 3-7A). Conversely, ridges commonly have crests that slope downward in one direction or the other, and the contour lines in that case form "V"s that point *down* the ridge or spur (Figure 3-7B).
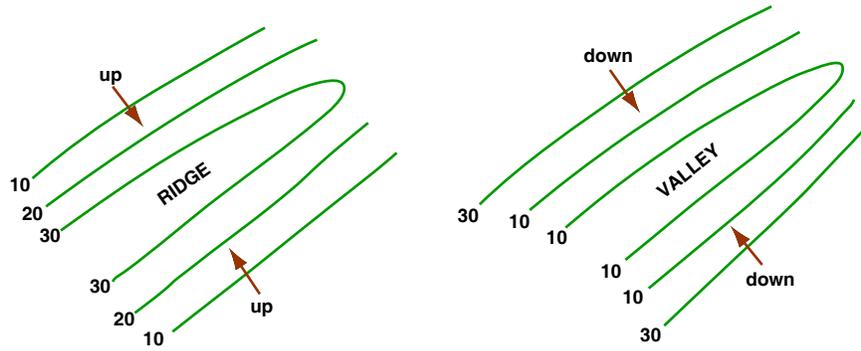

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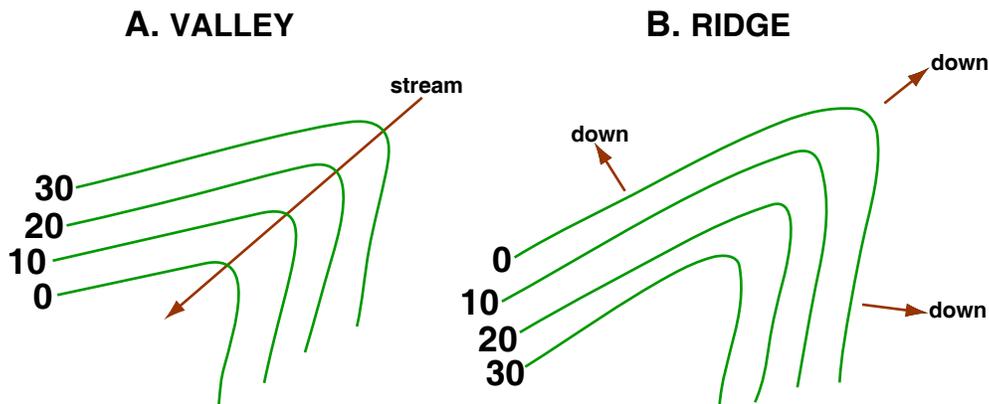
Figure 3-6. Contour lines for ridges and valleys.

Figure by MIT OCW

Figure 3-7: A) The "V"s of the contour lines point up valleys. B) The "V"s of the contour lines point down ridges.

6.6 How do you know the elevation of a hilltop from a contour map? The answer is: you don't, really, unless that information is supplied separately by being printed on the map! That's because the tippity-top in general lies on the "incomplete" contour interval above the uppermost closed contour. But at least you can bracket the elevation of the summit to be within one contour interval (Figure 3-8).
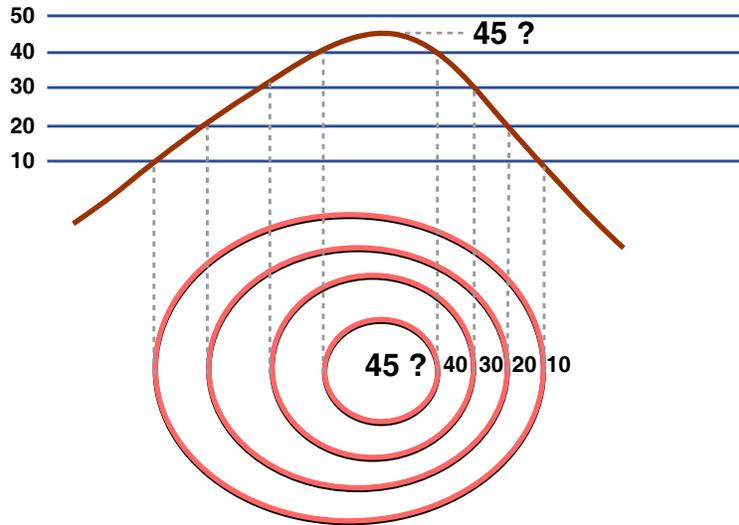
Figure 3-8. Estimating the elevation of a hilltop from a contour map.

6.7 Closed depressions on the land surface are the opposite of hilltops, but in most areas they are uncommon or even nonexistent. Closed contours for which the elevation decreases inward are denoted in a special way, by putting little perpendicular tick marks on the *downslope* side of the closed contour (Figure 3-9).

6.8 Overhangs (also not common) are also treated in a special way: the obscured segments of contour lines are either ignored or drawn as dashed curves rather than as solid curves (Figure 3-10).

6.9 Now think in terms of riding saddles or curvy potato chips, or, for those mathematically inclined, hyperbolic paraboloids (Figure 3-11). In all of these cases, one is dealing with a curved surface such that the intersection between the surface and a vertical plane is convex up in one direction and concave up in a direction approximately at right angles to the first. Such features on topographic maps are called **saddles** or **passes**. Saddles are common along ridges where stream valleys indent the ridge from two opposite sides.
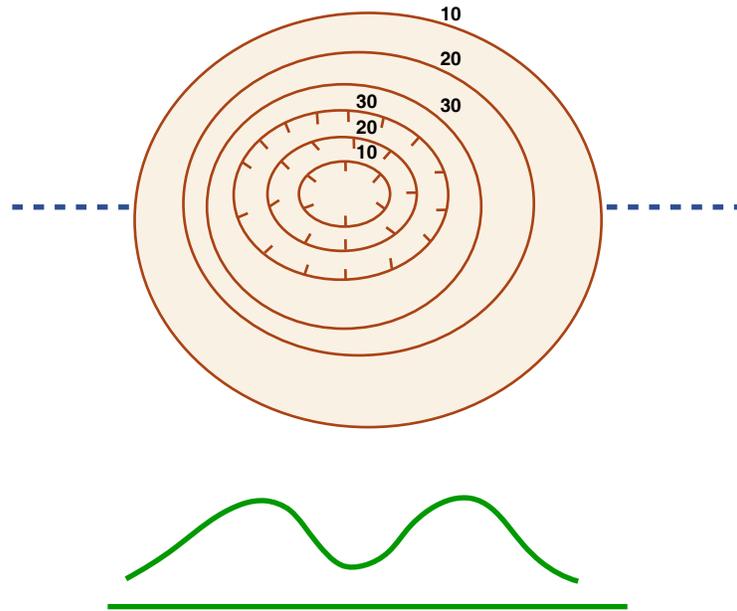
Figure by MIT OCW

Figure 3-9. How contour lines represent depressions.
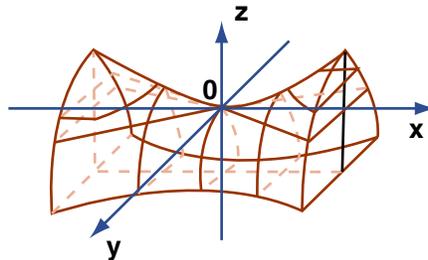

Figure by MIT OCW

Figure 3-10. How contour lines represent overhangs.

7. LOCATING YOURSELF ON THE MAP

7.1 When you are working outdoors with a topographic map, the map is likely to be much more useful when you are able to *locate where you are on the map*. That's a skill we won't be able to practice in this course, unfortunately. Below are some considerations for you to keep in mind, in case you are called upon to work outdoors with a topographic map.

7.2 One way of locating yourself is simply to *choose to be somewhere that corresponds to a readily identifiable feature on the map*, like a road intersection, a stream confluence, or a mountaintop. But that's overly restrictive: suppose you need to be somewhere not near such a feature?

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Hyperbolic Paraboloid

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = cz$$

Figure by MIT OCW

Figure 3-11. A hyperbolic paraboloid (a kind of "saddle") (From Burington, 1948.)

7.3 One technique, which is useful in arid and semiarid regions with substantial relief (by ***relief*** I mean *local differences in elevation from place to place*) is to look back and forth from map to land, several times, to relate the topography shown on the map to the topography you can see on the ground. It's a knack one acquires, usually readily and without much difficulty, by practice.

7.4 (I have not been able to develop a laboratory exercise to make that technique real to students in a classroom, although for some years I have intended to put into practice an idea that might be useful in that regard. Perhaps one of you might be moved to pursue the idea. I would like to build a small table-top model of some small area with rugged mountain-and-valley topography by blowing up the topographic map of the area, cutting successive layers of a sheetlike material like the foam-core sheets used to mount prints, by tracing the outline of successive contour lines on successive sheets of the foam core, then stacking the sheets together, gluing them one by one, and covering the entire "terraced" mass with a moldable material like wallboard joint compound, and finally sanding the surface smooth. With such a model, one could do two instructive things: (1) mark particular points on the model and ask students to locate the points on the map, and (2) mark particular points on the map and ask students to show the corresponding location on the model. It would be an extremely valuable teaching

tool. If anyone, perhaps with some experience along that line, is interested in working on such a model, let me know.)

7.5 The other technique, which is necessary in areas with low relief and/or heavy, view-obstructing vegetation, is *surveying*. You start from a known point on the map and run a survey line to the point of interest. This can be as crude as a compass-and-pace traverse or as sophisticated as a professional survey.

8. VISUALIZING THE LAY OF THE LAND

8.1 In working with topographic maps, one skill you need to develop is the ability to visualize the lay of the land from a topographic contour map. This involves picturing, in your mind's eye, what the map area would really look like, in a view from a low-flying airplane on a clear day, just from the information provided by the topographic contours. To make full use of a topographic map, you need to be able to do that.

8.2 Visualizing topography from looking at the topographic contours on the map is a skill you have to develop for yourself, by thought and lots of practice. Some people can do it much more easily than others. It's an exercise in using your "mind's eye", which is a useful skill in earth science, as well as in everyday life. (Think ahead toward when you might be wanting to remodel your home: can you picture the shape of your new kitchen, and how everything will fit together in it in three dimensions?)

8.3 To develop your skill in visualization, I will have a take-home exercise for you in which you will have to build a model of the earth's surface, out of modeling clay, just by looking at a topographic map of the area.

9. TOPOGRAPHIC PROFILES

It is often useful to obtain a vertical cross-section view of the land surface along a line that extends from one point on the land to another point. It's easy to construct such a profile if you have a topographic map of the area already available. Here's how to proceed:

(1) Pinpoint the two points at the end of the desired profile directly on your topographic map, and draw a faint pencil line between them.

(2) Lay out, on a blank sheet of paper, a corresponding faint pencil line near the top of the paper than extends from the starting point on the land surface to the ending point.

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(2) Establish a conversion ratio between the scale of the map and the scale of your cross-section line; then, as you pick points off the map, you can easily plot them along your cross-section line.

(3) For a large number of points along the profile line on the topographic map that happen to fall on topographic contour lines, pick off the elevations, and transfer them to your cross-section line on the sheet of paper.

(4) Connect the elevation points on your cross section with a smooth curve.

10. STREAM NETWORKS, DRAINAGE BASINS, AND DIVIDES

10.1 Tracing Stream Courses

10.1.1 In most areas of the world, except in the driest of deserts (and beneath glaciers), one can trace fairly easily on a topographic map the system of main streams and their tributaries. In some places streams "expand" into lakes, but the principle is the same.

10.1.2 *Permanent streams* are always shown as thin blue lines on official topographic maps, and *ephemeral streams* (those that flow only after a heavy rain) are often shown as dot–dash blue lines. Many well-defined valleys, however, which presumably would have streams flowing in them briefly after a heavy rain, have no streams shown in them. These are usually located in the headwaters of larger streams, which *are* shown on the map. So it's just a matter of extending the streams shown on the map farther upstream, to where valleys are no longer defined and the land surfaces slopes uniformly. (Remember about the "V"s of the contour lines pointing upstream in valleys.) You yourself can trace the courses of such streams by recognizing the position and downslope direction of such valleys.

10.1.3 Here are some points that should help you in tracing stream courses where there are valleys with no stream shown in them.

(1) Keep firmly in mind that *in a valley, the contours tend to "vee" up the valley*. You know that's happening by seeing that the "vees" point in the direction of increasingly high contour lines.

(2) *When you draw the stream course, make it pass directly through the crotch of each contour "vee"*. Streams tend to be curvy in real life, so don't hesitate to end up with a curvy stream.

(3) You are likely to find places where two tributary streams come together, at what's called a *confluence*, to form a main stream. With a margin of

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error of the space of one contour interval, it's easy to locate such a confluence: just *look for places where a contour with one "vee" is succeeded upward by a contour with two closely spaced "vees"* (Figure 3-12). The confluence lies somewhere between those two contours.
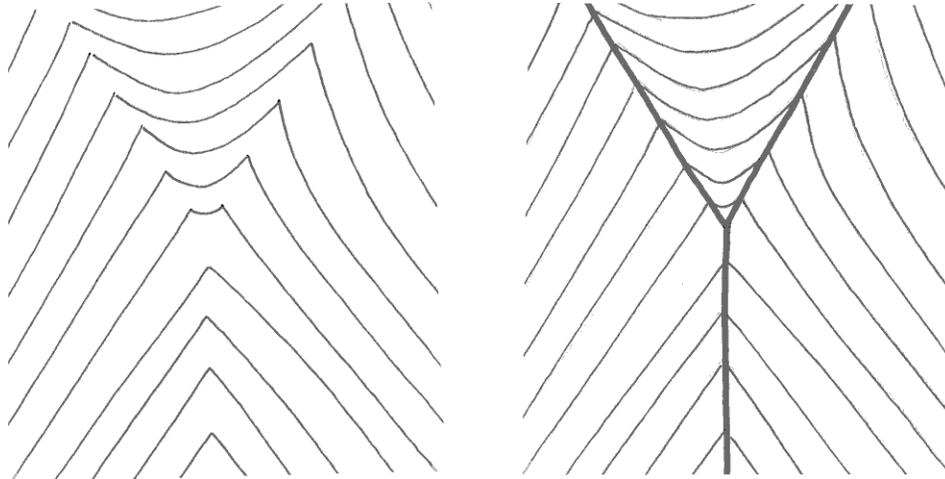

Figure 3-12. How you can locate the point of stream confluence by examining the "V"s of the contour lines.

10.2 Stream Divides and Drainage Basins

10.2.1 It should make sense to you that *the land area between individual streams is on at least slightly higher ground than the streams themselves*; if not, then the whole area would be a lake. (The exception to that last statement, fairly common in New England, involves low-lying wetlands bordered by or laced with well-defined streams.) Somewhere on that higher ground is a **stream divide**: *a continuously curving locus of points on the map separating an area of the land surface with drainage into one stream from an area of the land surface with drainage into another stream* (Figure 3-13).

10.2.2 Stream divides partition a given area of the land surface into **drainage basins**, each drained by a different main stream and its various tributary streams (Figure 3-13). Except in unusual situations, *the land area is partitioned exhaustively and non-overlappingly into drainage basins*.

10.2.3 If you are dealing with a fairly small area of the land surface, as

represented, for example, by a 7-1/2' topographic map, you run into the uncertainty about whether a stream that runs off the edge of your map, along with its drainage basin, runs into one of the other streams that runs off the edge of your map, at a point somewhere outside the area of your map, or into some other stream that doesn't even show up on your map. To ascertain that, you have to examine adjacent map areas. In the context of drainage basins and their size, it's important to know that.
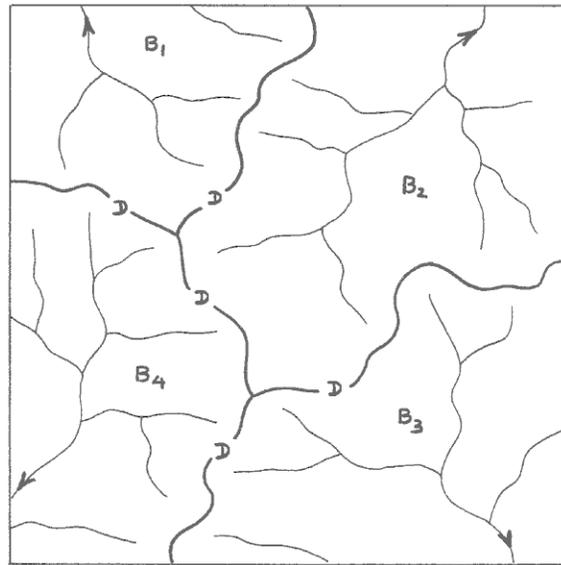

Figure 3-13. Drainage basins and drainage divides.

10.2.5 Just think in terms of traipsing around the land surface with buckets of water. If you pour the water upon the ground (and assume that it's going to run off to a stream rather than soaking in right on the spot), *to which stream does it flow*? Or, if you prefer something messier and but probably more exciting, imagine that the entire land surface is coated with ultra-slippery mud, and you let yourself slide on your backside down the slope toward a stream channel: which stream do you end up in?

10.2.6 What's going on is that the water, or you, are passing downward along what's mathematically called the **gradient**: *the route of steepest descent*. You can trace out such routes of steepest descent, from any given point on a sloping land surface as represented on a topographic map, by

drawing curves that are *everywhere normal to (i.e., at right angles to) the topographic contour lines* (Figure 3-14). Doing this by eye is not too difficult, once you get the knack of it.
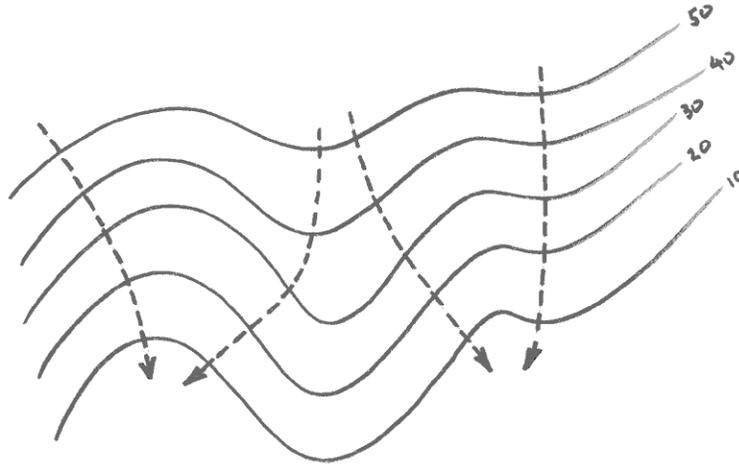

Figure 3-14. Gradient curves down a sloping surface.

10.2.6 Here are some considerations on divides. When two streams are separated by a well-defined ridge crest, locating the divide is easy (Figure 1-14A). When the ridge crest itself slopes (Figure 1-14B) or is broad and not well defined (Figure 1-14C), the job is not as easy. The divide between two streams that join together at a confluence at some point ends at that confluence point (Figure 1-14D). At their high ends, divides meet can meet at the "crotch" of a Y-shaped mountain slope (Figure 1-14E) or at the summit of a hill or mountain (Figure 1-14F).

19.2.7 What follows is a rather lengthy "home experiment" that should be useful to you if you are having trouble dealing with the concept of stream divides. Start with several cylinders, which could be tall soda bottles with tops and bottoms cut off, or fat mailing tubes (probably the best), or the cylindrical wooden posts from an old bedstead. (Mathematically, these are *circular* cylinders.) Make them all the same length, ideally several times the diameter of the cylinder. Cut each through lengthwise, along a plane parallel to the axis of the cylinder but offset a bit. Keep the bigger pieces and discard the smaller. These bigger pieces should look like fireplace logs that have been split down the middle but with imperfect aim. Now place them side by side on a rigid planar surface like a cutting board, with adjacent edges touching. The result should look a little like a giant washboard. (Washboards are a disappearing item; have you ever seen one, much less use one?) Put the cutting board with its cylinders in your bathtub, with one of

A

stream

ridge (divide)

stream

B

stream

ridge (divide)

stream

C

stream

divide
(somewhere)

stream

D

stream

divide

stream

E

stream

divide

stream

divide

stream

F

divide

stream

stream

divide

stream

divide

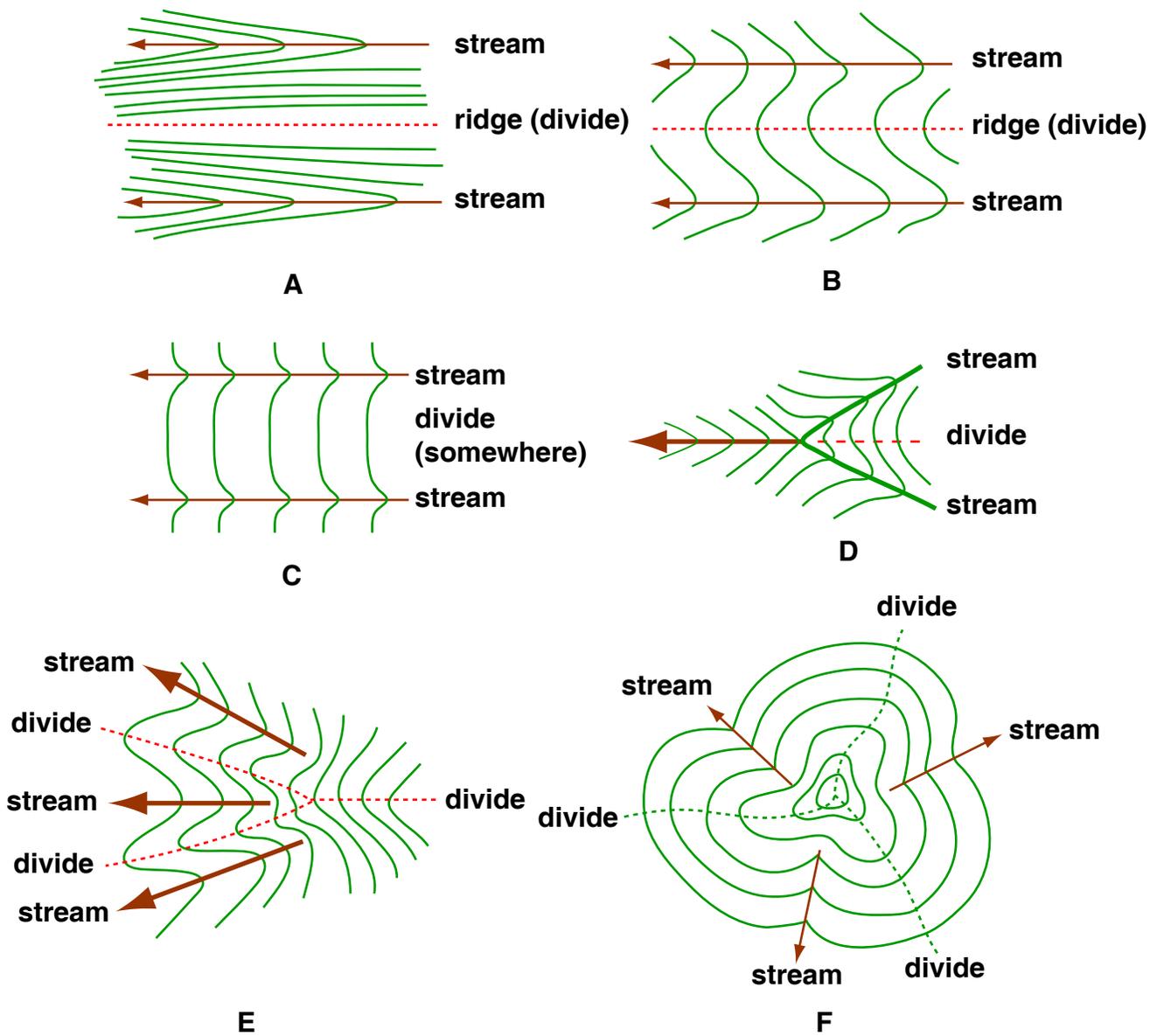Figure by MIT OCW

Figure 3-15. Considerations on stream divides. A) Two streams separated by a well-defined ridge crest. B) Two streams separated by a sloping ridge crest. C) Two streams separated by a broad and ill-defined ridge. D) Stream divides in the vicinity of a confluence. E) Two stream divides that merge into a single divide upslope. F) Stream divides meeting at the crest of a hill.

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slowly with water, in equal increments of depth, each time stopping to mark, with a permanent-ink felt-tipped pen, the water line on the surfaces of the cylinders. You will have to solve for yourself the problem of keeping the cylinders from floating away in the process. Now drain the water and view the bathtub from a point directly above, way up near the ceiling of your bathroom. What you want to try to see is a topographic map of your tilted-cylinder model. (You might have to squint a bit to help your imagination. If you are into photography, the best thing would be to put yourself high above the model and take a telephoto shot.) The result would look something like what is shown in Figure 3-16. (Incidentally, since the intersection of a circular cylinder with a plane that cuts the cylinder at some angle less than 90° to the axis of the cylinder is an ellipse, the contours on your "map" are segments of ellipses.) The model you've created is not a bad approximation to many real-life examples of valley-and-spur topography.
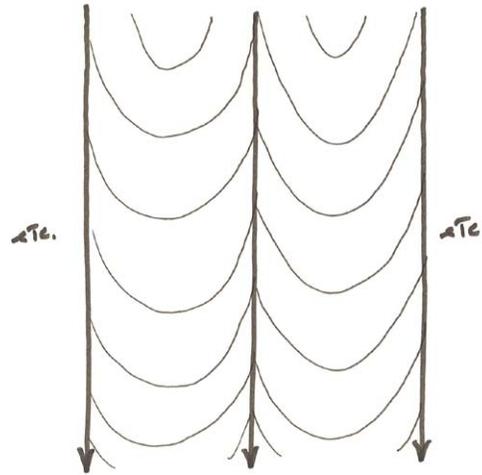

Figure 3-16. Contour lines in your bathtub cylinder-segment model.

10.2.8 Now that you have the map and model firmly in hand (or, more likely, in mind), think about the stream divides, and how they can be located. You know where they are, of course: they run straight down the "crests" of the cylinder segments, parallel to the "streams", which are nestled in the crevices between the adjacent cylinders. But for a deeper understanding of the nature of the divides, think about choosing a series of points along two adjacent streams and drawing lines up the sloping surface of the intervening cylinder, always along the path of steepest ascent (which, remember, is called the gradient) and is everywhere perpendicular to the topographic contours. You end up with a series of curves that bend around, as they pass upward, to be more and more nearly coincident with the divide itself. (In mathematical parlance, they approach the divide asymptotically.)

Even if your common sense had not told you at the outset where the divides are, you could draw them in with the guidance of this convergence of gradient curves (Figure 3-17). In Figure 3-17, which is just Figure 3-16 with the divides and gradient lines added, I have drawn the adjacent streams with heavy solid lines, the gradient curves with light dashed lines, and the divide with a heavy dashed line.

Figure 3-17. Your cylinder-segment model, with divides and gradient curves shown in addition to the contour lines.

10.2.9 You can pursue the same line of thought in reverse, by imagining that you start at various points on or very near the divide and rolling little marbles down the sloping surface of the cylinder. If the inertia of the rolling marbles is neglected, they follow a gradient curve as they roll down. (You might have to use sticky marbles, so as to slow them down to the point where they have negligible inertia; otherwise they would tend to overshoot the curve and try to continue straight ahead.) If you put your marble precisely on the divide, it would roll straight down the divide! You're not likely to be successful at that, though; it's a bit like trying to balance a vertical pencil on its sharp point.

10.2.10 What's the point of the foregoing exercise? It gives you a useful and fundamentally sound means of locating divides on a real topographic map: just *start at a number of points along the two adjacent streams, draw the gradient curves upward, and place the divide along where the gradient lines converge*. Figure 3-18 is an example from a actual topographic map. Again I have drawn the adjacent streams with heavy solid lines, the gradient curves with light dashed lines, and the divide with a heavy dashed line. Don't be concerned about the unequal spacing of the gradient curves on either side of the divide: I just arbitrarily drew only those that start from where the streams cross contours. There's an infinity of such gradient lines, so the spacing doesn't matter at all.

Figure 3-18. Locating a stream divide by drawing gradient curves upward from two adjacent streams.

10.2.11 This exercise points up an effect that goes beyond just the location of the divide: it tells you that *runoff from the land surface during a heavy rain might take a rather roundabout route to the nearest stream*, if the point is located near the divide.

10.2.12 You might also imagine taking this exercise to its logical extreme: instead of cylinders, use *prisms* (shaped like steeply pitched roofs). Then the resulting topographic map would look like the one shown in Figure 3-19. Now the

divides are *really* obvious—but the principle is the same. The gradient curves are straight lines passing upward along the paths of steepest ascent from the streams, to meet the divide at a sharp angle. Now it would be even *more* difficult to roll a marble down the divide! Such topography is fairly representative of that of areas called **badlands**, where *the material at the surface is so soft and erodible that streams become densely developed down to very small scales*, and divides are quite sharp.

Figure 3-19. Your cylinder-segment model, modified by using prism rather than cylinders.

10.2.13 Now, briefly, back to the real world. *What happens to divides when you follow them upslope?* Figure 3-20 shows a hill down which three stream flow. The divides between the streams merge to a single point: the hilltop point.

10.2.13 Finally, here are some considerations on *the divides between tributaries of a given stream*. This pushes us out to the edge of what I want you to understand about topographic maps, so if you find yourself uncomfortable about following the material below, do not be concerned.

10.2.14 Figure 3-21 shows a stream with two tributaries. The stream and its tributaries lie in a bowl-shaped depression on a hillslope; note the curving ridge line at the top of the map, with gentle saddles just above the upvalley termini of the two tributaries. The main divide between this drainage system and whatever is on the other side of the hill is shown as a heavy dashed line. In addition to that main divide, however, *there is a divide between the two tributaries*. Its lower end is at the confluence of the tributaries, and it meets the main divide at the crest of the mountain ridge. But that's not the end of the story: you can locate *two further divides, one for each tributary, that separate areas that drain into the main stream via the tributary from areas that drain directly into the main stream.* Those divides also must meet the confluence at their lower ends.

Figure 3-21. Divides between tributaries of a given stream.

10.3 How More Contours Would Remove Uncertainties

10.3.1 If you work with topographic maps in the take-home exercises, you will probably feel some frustration and uncertainty in tracing streams and locating divides in certain areas of the map where relief is low and contours are thereby spaced far apart. It might be instructive for me to point out that *such uncertainties*

could always be resolved by use of a map with a sufficiently smaller contour interval. (This is merely a conceptual matter, however: such maps are seldom actually available. Of course, you could add such contours to your map, qualitatively, by going out to the area in question and studying about the lay of the land, just by eye.)

10.3.2 As a first example, look at an area with a low and not very well-defined ridge (Figure 3-22A). If you could somehow decrease the contour interval by a factor of two (that is, doubling the number of contour lines), the topography of ridge becomes much better defined on the map (Figure 3-22B).

Figure 3-22. A) A poorly defined ridge. B) The ridge becomes better defined when the contour interval is decreased.

10.3.3 As a second example (Figure 3-23), reducing the contour intervals can make saddles appear where none are shown on the original map. This statement, strange as it might seem at first hearing, should make sense to you: if there is a little rise or nubbin on a descending spur ridge, and the vertical positions of the contours happen not to intersect it, it won't show as a closed contour, just a little area with locally wider spacing of contour lines. Just by cutting the contour interval in half, thereby doubling the number of contours, two additional saddles magically appear.

Figure 3-23. A) A spur, with no saddles shown. B) Decreasing the contour interval by a factor of two makes saddles appear on the map.

10.3.4 This points up an effect you should always keep in mind when using topographic maps: *topographic maps are in almost all cases generalizations.* The larger the scale of the map (that is, the smaller the area represented), and correspondingly the smaller the contour interval, the more detail you are going to see in the topography. Pushed to its logical extreme, the map might show the geometry of individual pebbles and sand grains on the surface! There might, of course, be valid reasons, of research and study, for using a map with that large a scale, but it would be a very specialized matter.

11. GEOLOGIC MAPS AND CROSS SECTIONS
11.1 Rock Units

11.1.1 Field geologists who study and map the bedrock that underlies an area of the land surface attempt to recognize rock units, which they can then

represent on geologic maps. Rock types are not randomly arranged in the Earth's crust but tend to exist in distinctive bodies called **rock units**. Rock units are *large three-dimensional bodies of rock with compositions that are distinctive and different from adjacent rock units*. Rock types vary widely in size, shape, composition, and origin.

11.1.2 Rock units are formed by the action of some particular process or set of processes—for example, sediment deposition, magma intrusion or extrusion, or metamorphism. Rock units can consist of sedimentary, igneous, or metamorphic rocks. The defining characteristic of a rock unit is that certain processes operate for some period of time to produce a body or mass of rock with fairly uniform rock type, or perhaps a consistent alternation of two or more rock types.

11.1.3 Here are some examples of the kinds of rock units a geologist might recognize in the field:

- A succession of sedimentary layers of one or several rock types, deposited in some distinctive sedimentary environment. The thickness of such a unit might range from several meters to many thousands of meters, and the lateral extent might range from hundreds of meters to a few hundreds of kilometers.

- A succession of volcanic rocks with distinctive composition. Such units might be as thin as a single lava flow (which could be as thin as a few meters) or as thick as many hundreds of meters. Such units might be interbedded with sedimentary rock units as well.

- A single igneous intrusive body. Such intrusive units cut across other rock units that they intrude.

- A unit of metamorphic rocks of a particular composition. Such a unit might have extremely complicated geometry, owing to intense deformation accompanying metamorphism. The intensity of metamorphism might vary systematically from one area to another within the metamorphic rock unit.

11.1.4 The minimum dimensions of a rock unit can be as small as meters or even decimeters, in the case of thin igneous dikes, for example. Units that small would not ordinarily be represented on a geologic map unless the purpose of mapping is to display the geology of a very small area in great detail, as for example at a major construction site.

11.1.5 Rock units are in contact with each other across three-dimensional surfaces or relatively thin zones of transition or gradation. The lines that represent contacts between rock units on a geologic map are the lines of intersection

between the actual three-dimensional contact surfaces and the land surface itself. Recognizing and interpreting the nature of contacts between rock units is central to geological fieldwork. It's largely by interpretation of the nature of such contacts that the geologic history of an area is worked out.

11.1.6 Many rock units receive formal names. The basic sedimentary rock unit (and also metamorphic and volcanic rock units) is the ***formation***. Formations have two-part names: the first part is a place name, like a town, a river, or a mountain, and the second part is either the word "Formation" or a rock term like "Sandstone". Volcanic and metamorphic rock units have similar two-part names. Formations can be subdivided into ***members***, which can have either formal names or just informal names. Related formations can be lumped together into larger units called ***groups***, which receive place names in the same way as formations. Intrusive igneous units, especially large units, can have formal names, but smaller units, even though they might be mappable, usually are not formally named.

11.2 Geologic Maps and Cross Sections

11.2.1 A ***geologic map*** is *a map that shows the distribution of bedrock that is exposed at the Earth's surface or buried beneath a thin layer of surface soil or sediment*. A geologic map is more than just a map of rock types: most geologic maps show the locations and relationships of rock units.

11.2.2 Each rock unit is identified on the map by a symbol of some kind, which is explained in a legend or key, and is often colored a distinctive color as well. Part of the legend of a geologic map consists of one or more columns of little rectangles, with appropriate colors and symbols, identifying the various rock units shown on the map. There is often a very brief description of the units directly in this part of the legend. The rectangles for the units are arranged in order of decreasing age upward. Usually the ages of the units, in terms of the standard relative geologic time scale, is shown as well.

11.2.3 All geologic maps convey certain other information as well. They show the symbols that are used to represent such features as folds, faults, and attitudes of planar features like stratification or foliation. They have information about latitude and longitude, and/or location relative to some standard geographic grid system. They always have a scale, expressed both as a labeled scale bar and as what is called a "representative fraction", 1:25,000 for example, whose first number is a unit of distance on the map and whose second number is the corresponding distance on the actual land surface.

11.2.4 All geologic maps (except perhaps very special-purpose maps that show all the details of an area that might be the size of a small room!) involve some degree of generalization. Such generalization is the responsibility of the geologist who is doing the mapping. Obviously, it is not practical to represent

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features as thin as a few meters on a map that covers many square miles: the width of the feature on the map would be far thinner than the thinnest possible ink line. The degree of generalization necessarily increases as the area covered by the map increases. You could easily see this for yourself if you have access to a geologic map of some small area together with the corresponding geologic map of the entire state: the detail of the small area on the state map would be much less than on the full map of that small area.

11.2.5 Most geologic maps are accompanied by one or more vertical ***cross sections***, which are *views of what the geology would look like in an imaginary vertical plane downward from some line on the land surface*. These cross sections are constructed by the geologist after the map is completed. Their locations are selected so as to best reveal the three-dimensional nature of the geology. Cross sections are constructed by projecting downward the geologic features and relationships that are observed at the surface. Constructing cross sections requires the geologist to be able to visualize the geology in his or her mind. The degree of certainty about the geology shown on the cross section decreases downward with depth below the surface.