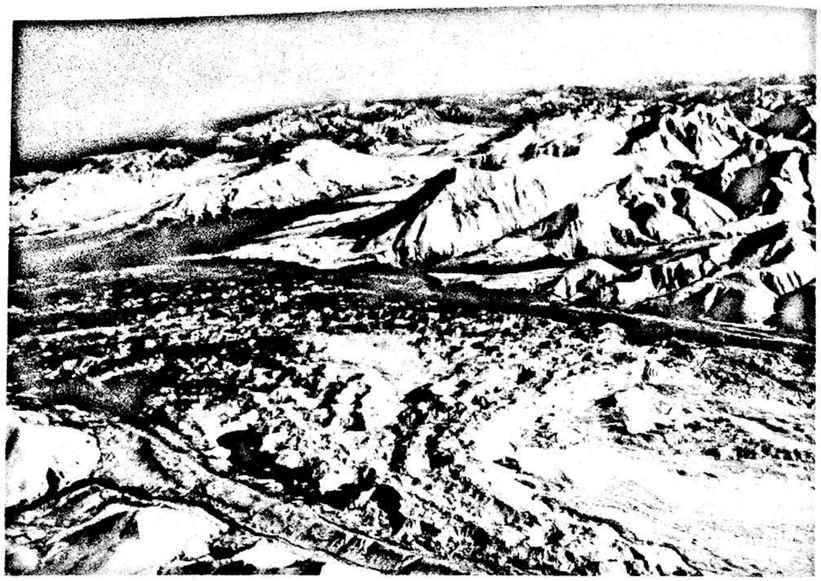


Glaciers are huge sheets or rivers of ice that can round peaks, carve valleys, and create hills of rock debris.

CHAPTER 25
Environmental Factors in Landscape Development

You will know something about landscape development if you can:

1. Describe the effects of uplifting and leveling forces on the various landscape characteristics.
2. Describe the effects of climate on the various landscape characteristics.
3. Describe the effects of bedrock on the landscape characteristics of an area.

In our investigation of landscape development we have taken the usual first steps in every scientific inquiry – we have looked around us, made observations, and attempted to classify them. We have observed a variety of landscape types and we have devised ways of describing and measuring their characteristics.

We are now ready for the next stage – a search for the "why" and "how" of landscape differences. We are quite sure that we live on a changing planet. We know quite a bit about the changes going on at the surface as well as deep within the earth. Can we use that knowledge to account for the landscapes we see today and perhaps to predict what will happen to them in future ages?

INTRODUCTION

As defined in Chapter 24, the landscape of a region is the association of the physical features of the earth's surface in that region. We also learned that there are certain measurable characteristics that can be used to describe all landscapes. These characteristics are hillslopes, stream patterns, and soil associations. We are now ready to investigate those factors in the environment that act to shape the landscape and to produce the characteristics of the various types of landscapes.

The environmental factors to be considered include uplifting and leveling forces, climate, bedrock, and man's activities. Of these four factors, the first three are all due to natural processes. These three factors will be investigated in this chapter. The fourth factor, human activities, will be considered in Chapter 26.

The overall process of landscape development is very complex. Although there are several factors that can and do influence landscapes, they may not all be operating at a particular time and place. As we investigate the interactions of the environmental factors with landscape characteristics, you may find it helpful to keep a "running account" of the effects of each factor on each characteristic. The table, or grid, shown in Figure 25-1 illustrates one method of organizing the information in a written record. You may want to make a large copy of this table and fill it in as we go along.

There is no practical way to determine the relative importance of the environmental factors, so the order in which they are listed has no particular importance. Likewise, the landscape characteristics are not listed in any particular order. As we investigate each interaction, we can summarize the information gained and place it in the box that represents that interaction. An example of such an interaction would be the effect of climate on stream patterns. This information would be entered in the box in row 2, column 2. After our investigations are completed, we should be able to summarize the effect of any given environmental factor on all of the landscape characteristics. We should also be able to determine how a single characteristic is affected by each of the environmental factors.

Figure 25-1. Relationships between environmental factors and landscape characteristics.

ENVIRONMENTAL FACTORS	Hillslopes	Stream patterns	Soils
Crustal change–uplift and leveling			
Climate			
Bedrock			
Human Activities			

UPLIFTING AND LEVELING FORCES

Wherever hillslopes exist, the forces of weathering, erosion, and deposition are acting to reduce the slopes and make the surface horizontal. These forces are called *leveling* forces. They are also referred to as *destructional* forces, because they tend to destroy variations in the landscape. The leveling forces act almost entirely at the interfaces between the three "spheres" of the earth.

Although the leveling forces are acting continuously to bring the land down to a uniform, flat surface, they never do accomplish this result. The reason is that there are *uplifting*, or *constructional*, forces that undo the work of the leveling forces. These forces operate beneath or within the crust. They include volcanic activity, isostasy, earthquakes, ocean-floor spreading, and continental drift.

As far as landscapes are concerned, the effects of these two groups of forces are opposite. Uplifting tends to increase elevations and also to roughen, or increase the relief of, the surface. Leveling tends to reduce elevations and smooth the surface. In any particular region at any particular time the rates of uplift and leveling are likely to be different. If the uplifting forces are raising the surface faster than the leveling forces are lowering it, we say that the uplifting forces are *dominant*. In other cases, the leveling forces may be dominant. In some places, the rates of uplift and leveling may be approximately equal, and the landscape will be in a state of dynamic equilibrium.

How can we determine which group of forces is dominant in a region or whether they are in balance? The processes are far too slow for us to observe the changes directly. However, we can observe the present characteristics of the landscape and infer whether uplift, leveling, or neither is dominant at the present time. Let us consider the different effects of uplift and leveling on the various landscape characteristics.

Hillslopes. In regions where uplifting forces are dominant, hillslopes reflect this fact in several ways. Gradients are generally steep, and free face predominates. The other hillslope characteristics—waxing, waning, and debris slopes—are relatively small or even nonexistent. An example of a situation in which uplift is dominant is found where vertical movement along a fault is occurring on a large scale. One result of such crustal movement may be the formation of *fault block mountains*, as illustrated in Figure 25-2. Figure 25-3 is a photograph of a typical landscape in which this kind of uplift is apparently occurring. The unbranched, V-shaped gullies in the free face indicate that erosion is just beginning. Sediment carried down the large gulley in the center of the photo has come to rest on the valley floor in a characteristic pattern called an alluvial fan. True debris slopes are absent. Uplift has occurred here at a much faster rate than leveling.

Figure 25-2. Formation of a fault-block mountain.

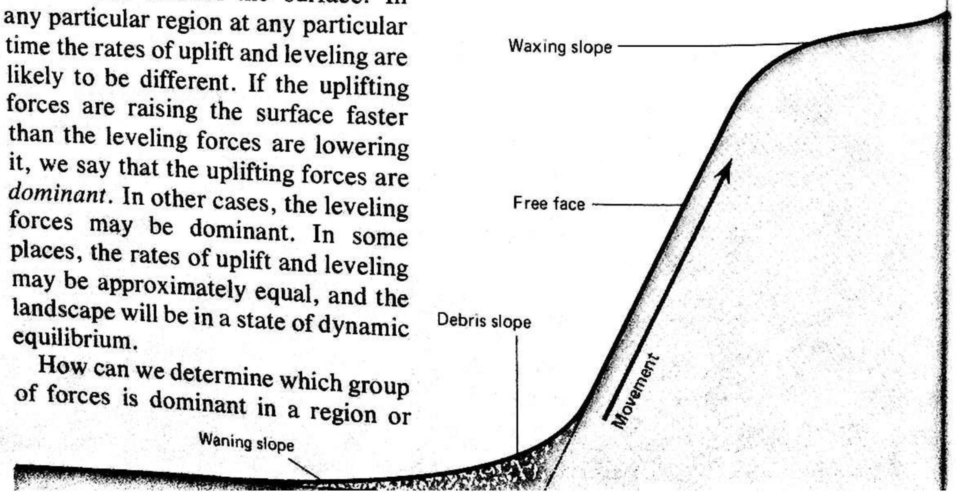


Figure 25-3. Region in which uplift has occurred at a faster rate than erosion.

In Figure 25-4 we see a region where leveling has apparently kept in step with uplifting. The many branching gulleys and stream beds indicate that erosion has been going on for a fairly long time. The debris slopes, waning slopes, and valleys between the hillslopes are larger than in the region of Figure 25-3. Much sediment has been transported and deposited in the foreground. Still, the free face of the hillslopes is extensive, and there is little waxing slope. So we can conclude that uplift has been opposing the effects of leveling and maintaining the features of a recently uplifted landscape.

We have previously seen examples of regions where leveling and deposition are clearly dominant over uplift. Figure 15-13 on page 298 is typical. Erosion by running water is the chief leveling force. Note the gentle gradients, broad waxing slopes, extensive waning slopes, and almost complete absence of free face on the hillslopes still remaining in this landscape. At this time, very little uplift, if any, is occurring here.

Earlier we saw how uplifting forces can change the earth's surface in regions where zones of weakness, or faults, are present. These forces can thrust part of the crust upward along a fault. Uplifting forces can also cause parts of the earth's surface to be elevated without faulting taking place. Internal pressures can cause the crust to *warp* or *fold*. These internal pressures may be exerted vertically, hori-

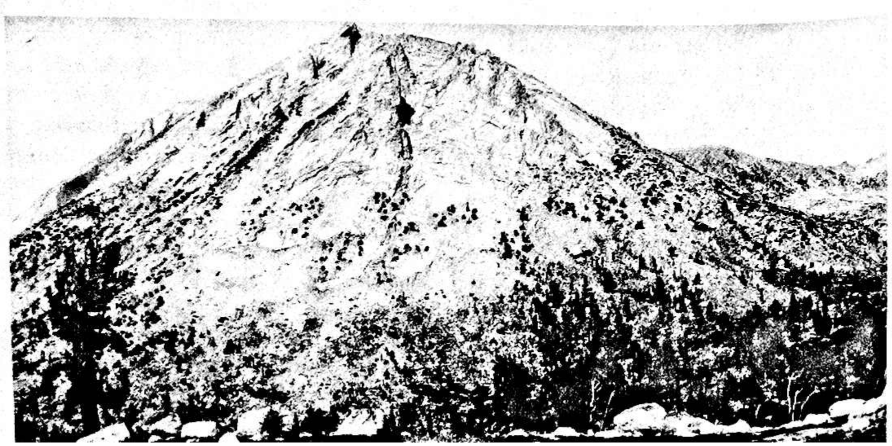
Figure 25-4. Region in which uplift and erosion have occurred at about the same rate.

zontally, or in both directions at the same time. If these pressures are exerted over a large enough area, extensive regions of the crust may be affected. The result may be a vertical uplifting of a region to form a plateau, or a gentle warping of the crust to form an arch that extends over several hundreds of kilometers. Often, less extensive areas of the earth's crust are deformed by these internal pressures.

If the internal pressure is exerted vertically, the crust may warp upward to form a circular or oval-shaped hill called a *dome* (see Figure 25-5). When internal pressures are exerted horizontally, the result may be a folding of the crust. Such folding can produce a single, elongated hill, or ridge. In other cases, the crust is "wrinkled" into several folds, which results in a series of ridges, as illustrated in Figure 25-6.

The photograph in Figure 25-6 is an aerial view of a series of ridges in the Appalachian Mountains near Harrisburg, Pennsylvania. The streams in this landscape have a surprising characteristic. Instead of following the valleys between the folds, as we might expect them to do, they have

Figure 25-5. A dome.



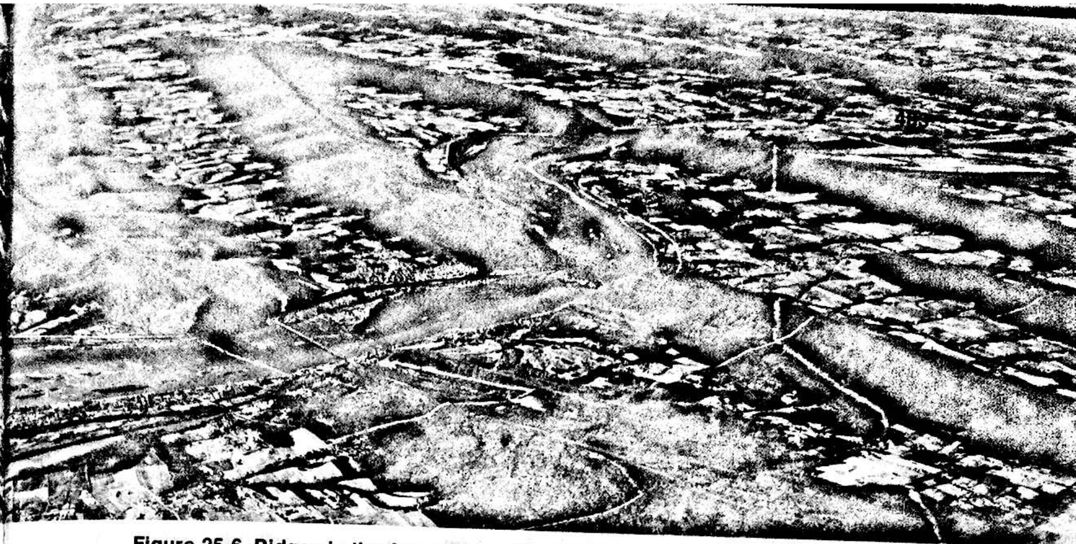


Figure 25-6. Ridges in the Appalachian Mountains where streams cut across the mountains.

cut into and across the uplifted folds. How could streams have done this?

By studying the exposed rock layers and the fossil record they contain, geologists have reconstructed the history of this region. The methods are similar to those used to unravel the earth history puzzle in Chapter 23 (page 451). The cross-sectional models in Figure 25-7 show the important stages of the landscape development of the region that have been inferred. At one time there were mountains that had been formed by folding of layers of rock. These mountains had been eroded down almost to

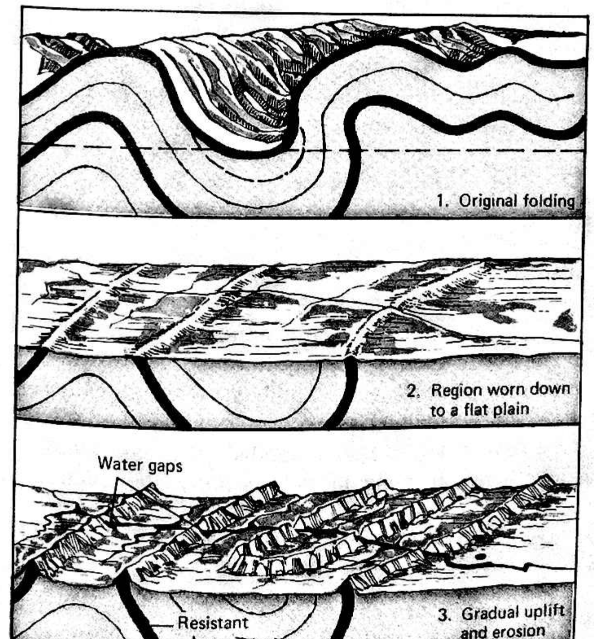


Figure 25-7. Stages of landscape development near Harrisburg, Pennsylvania. The mountains produced by the original folding of the area (1) were worn away by weathering and erosion, producing a flat, plainlike landscape (2). Gradual uplift of the region has resulted in the present landscape (3).

a flat plain, sloping gently to the east. Streams flowed across this plain, following the downward slope. Then the entire region was uplifted again by folding. However, this process was so slow that the streams did not have to leave their channels. They were able to cut down into the folds as fast as they were raised and thus maintain their generally eastward flow. A valley cut across a ridge by a stream is called a *water gap*. Several water gaps in the Appalachian Mountains became important trails and roads across the mountains during the westward expansion of our nation.

Whatever the manner in which uplift occurs, the effect of uplifting forces is to increase the relief of a portion of the earth's surface. This, in turn, changes hillslopes. Their gradients become steeper. As we shall see, these changes have a marked effect on the other environmental factors that influence the shape of the landscape.

Shoreline Landscapes. The shape and characteristics of land adjacent to a large body of water is called a *shoreline landscape*. For our purposes, we will consider a shoreline landscape to be one adjacent to the sea, although lakeshore landscapes are also affected, to a much lesser degree, by many of the same factors that shape a seashore landscape. As you might expect, shoreline landscapes have certain features and characteristics not found in inland landscapes. One reason for this fact is that the leveling activity, or erosion, that occurs along a shoreline is due mainly to wave action, that is, water driven by wind rather than gravity.

Base level in a shoreline region is sea level, and elevations of the land are expressed relative to sea level. Shorelines are usually classified according to the *change* in elevation of the land surface relative to the surface of the water. Such changes can be due to vertical movements of the land (uplift or subsidence) or changes in sea level. Thus, the three main classes of shorelines are shorelines of emergence, shorelines of submergence, and neutral shorelines.

Shorelines of emergence. As the name suggests, shorelines of emergence are formed when part of the ocean floor near the border of a continent emerges to become part of the landscape. This emergence can be due to crustal uplift, or it can be due to a drop in the level of the ocean. In shorelines of emergence, the water line takes a position against what was once part of the sea floor. Generally speaking, shorelines of emergence are fairly straight or regular.

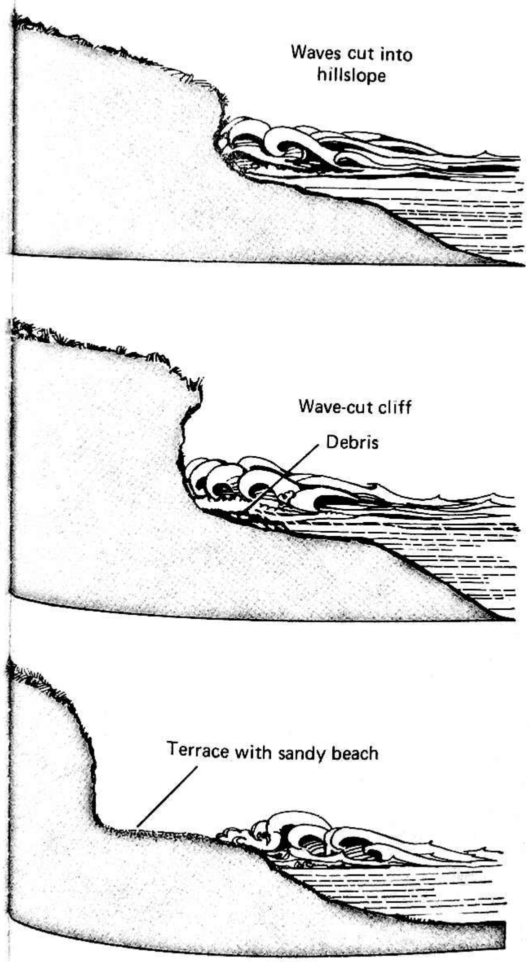
In some areas, the sea floor adjacent to the continent is part of the continental shelf. The surface of the shelf is relatively smooth and has a gentle slope. Therefore, if part of this shelf emerges, the shoreline landscape produced is a low, smooth, gently sloping coastal plain.

In areas where the sea floor drops sharply, emergence produces a steeply sloping shoreline. In this case, wave action undercuts the hillslope, making it even steeper. Eventually, the oversteepened slope breaks away, forming a *wave-cut cliff*. Wave action and weathering further break down the accumulating debris, reducing it to sand. The sand can be transported by currents and distributed along the shoreline and carried offshore to

greater depths in the water. This entire process is summarized in Figure 25-8.

One result of this process is to move the hillslope inland. At the same time a fairly flat beach or *terrace* develops at the base of the hillslope. We have seen an example of this in Figure 19-5, page 370. If emergence occurs at intervals, with periods of stability between them, a series of wave-cut cliffs and terraces at different elevations, looking much like a flight of steps, may develop.

Figure 25-8. Stages in the development of a wave-cut cliff and terrace.



Shorelines of submergence. Whenever the land adjacent to the water subsides, or when sea level rises, a shoreline of submergence is formed. The new water line takes a position along what was a contour of the dry land. Most shorelines of submergence are quite irregular. The outline of the shoreline will depend on what the topography of the land was before submergence.

If the topography consisted of a series of hills, and valleys, submergence produces a very irregular shoreline. Former valleys become deeply indented bays, hilltops become islands, and ridges become promontories or peninsulas. If the topography consisted of a coastal plain of low relief, the new shoreline will be fairly regular, with numerous low-lying offshore islands.

A special type of shoreline of submergence is formed in coastal regions that have been deeply eroded by valley glaciers. When such a coastline submerges, deep, steep-walled, narrow estuaries called *fiords* are formed.

Neutral shorelines. Neutral shorelines develop when there is no relative change in elevation between the land and the water. In such cases, the shorelines tend to become built out further into the water as streams bring sediments down to their mouths. Bays become filled in and deltas or sand bars may form. If there is volcanic activity near the shoreline, the shoreline will be built out by accumulations of debris from the eruptions.

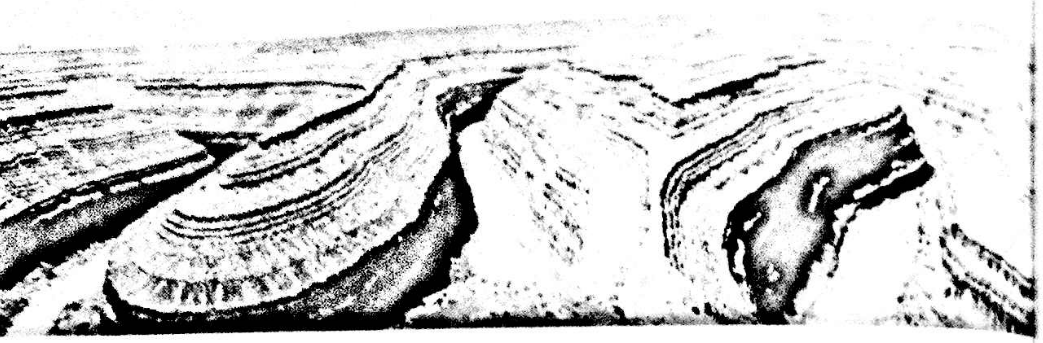


Figure 25-9. Entrenched meanders in the San Juan River, Utah.

Stream Patterns. As discussed in Chapter 24, stream systems can be described in terms of several characteristics—stream gradient, drainage pattern, and drainage density. Of these three characteristics, the one that is *most* affected by uplifting and leveling forces is gradient.

Whenever uplifting forces produce an increase in hillslope, stream gradients are also increased. Increasing stream gradient increases the velocity, and therefore the eroding power, of a stream, as we learned in Chapter 15. Thus, even as uplifting forces are raising the elevation of the surface, they are also increasing the "leveling" ability of one of the most effective erosional agents—that of running water.

The photograph in Figure 25-9 provides dramatic evidence of the effect that uplift can have on the eroding power of a stream. You can see that the stream in the photograph has a meandering course. As you learned in Chapter 15, a meandering course is usually associated with a river that is flowing over a relatively flat region that is quite near base level. Such was the case with this river before the region underwent uplift. When the region was uplifted, the stream gradient became steeper and the erosional power of the stream was increased. The "rejuvenated" stream cut vertically into the bedrock, producing the steep-sided *incised*, or *entrenched, meanders* shown here.

We have just seen a second example of uplift causing a stream to erode deeper into its channel, but without changing its course. (The earlier example was the development of water gaps described on page 484.) However, uplift can also produce changes in stream channels and drainage patterns. The patterns that develop are greatly influenced by the characteristics of the bedrock in the region. We will therefore postpone a discussion of drainage patterns until we reach the subject of bedrock composition later in this chapter.

Soil Formation. The formation of soil is influenced mostly by climate

and bedrock. The effect of uplifting and leveling forces on soil and its development is confined mainly to determining regions of erosion and deposition. As discussed in Chapters 15 and 16, erosion is generally dominant in regions of high elevation and steep hillslopes and stream gradients. Thus, the earth materials from which soils are formed and developed are being transported from these regions. On the steep hillslopes of mountainous regions, soils are generally thin and poorly developed. On the other hand, deposition is dominant in regions of low elevation and gradual hillslopes and stream gradients. As noted in Chapter 15, this is where deep soils are likely to form.

Crustal change may have a more direct effect on soils when volcanic activity is involved. Volcanic eruptions result in new rock material being deposited on the earth's surface. This new rock material can be weathered to form soil. Volcanic material is often rich in plant nutrients, and as weathering progresses, plants can take root and flourish on the volcanic soil. As more and more plants grow, the soil becomes deeper and more fertile.

In summary, uplifting and leveling forces influence landscape characteristics directly and indirectly. These forces most directly affect surface elevations and hillslopes. In turn, changes in elevation and hillslope gradients influence other factors, such as stream gradients (and, thus, their eroding powers) and soil formation. As you can see, there is a great deal of interaction and interdependence among the processes that act to shape the landscapes.

SUMMARY

1. Landscapes seem to result from the interaction of two groups of opposing forces. These groups are the uplifting, or constructional forces, and the leveling, or destructional, forces.
2. In a particular landscape, one of the groups of forces may be dominant.
3. Shorelines are classified according to the change in elevation of the land surface relative to sea level. The three main classes of shorelines are shorelines of emergence, shorelines of submergence, and neutral shorelines.
4. The rate of crustal change, either uplift or subsidence, may alter, modify, or produce characteristic hillslopes, stream patterns, or soil conditions.

CLIMATE

As you will recall from Chapter 13, climate refers to the average conditions of temperature and moisture in a region over an extended period of time. In this section, we will investigate the influence that climate has on the various landscape characteristics.

Hillslopes. The photographs in Figures 25-10 and 25-11 were taken in two different regions of the United States. The landscape in Figure 25-10 developed in a region where the ratio of precipitation to potential evapotranspiration (P/E_p) is quite high

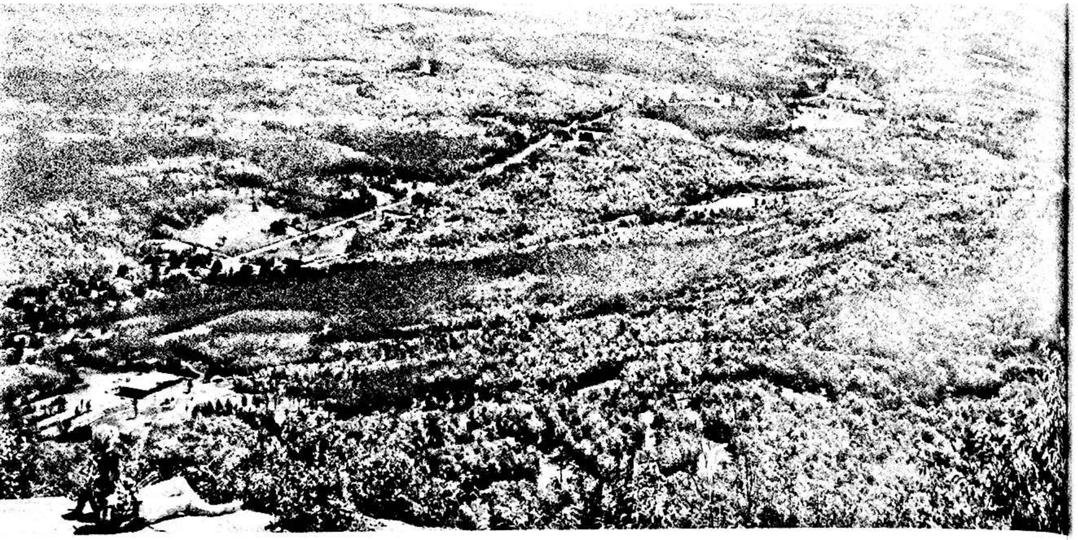


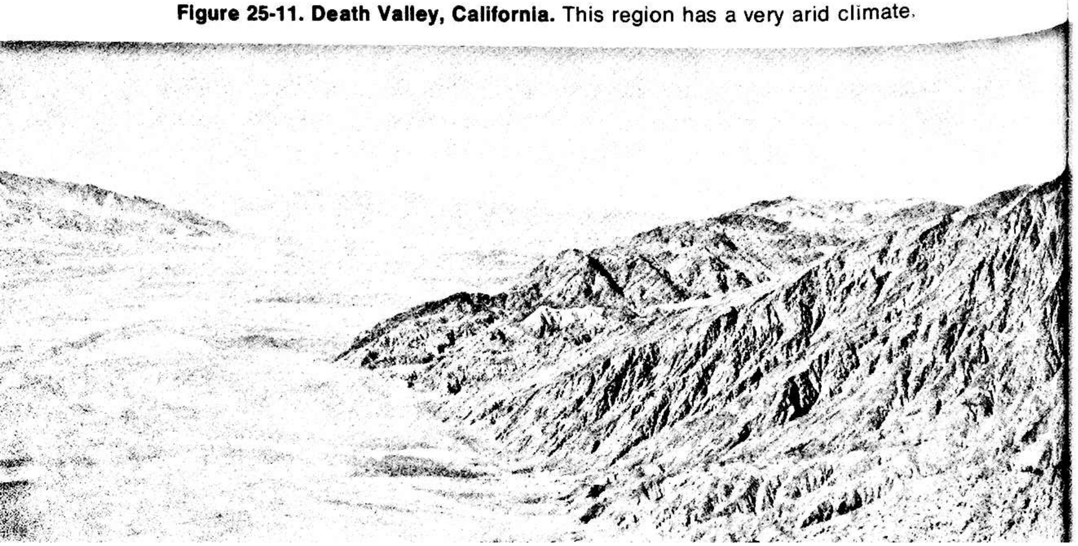
Figure 25-10. Catskill Mountains of New York State. This region has a humid climate.

(see Chapter 13). This region has a humid climate. On the other hand, the region shown in Figure 25-11 has an arid climate, with a low P/E_p ratio.

One striking difference between the two landscapes is the sharpness of landform features. Arid landscapes have angular or sharp hillslope features, while hillslopes in the humid environment appear more rounded. Free face is much more prominent on arid hillslopes.

As stated earlier, it is just about impossible to pick out one factor as being responsible for producing the particular features of a landscape. Rather, the interaction of all of the environmental factors must be considered. However, the reasons for the differences between the characteristics of the hillslopes shown in the two photographs can be summed up quite accurately in a single word—*moisture*. Moisture is the key to the

Figure 25-11. Death Valley, California. This region has a very arid climate.



processes of weathering, erosion, and soil formation and development. Moisture is also vital to the growth and support of vegetation.

These differences between hillslopes in arid and humid climates are observed all over the world. We may safely infer that the differences are related to the difference in the availability of moisture. How does the amount of moisture influence the landscape development?

Where mountains have formed in an arid region, weathering is most likely to be physical. As explained in Chapter 14, moisture is needed for most processes of chemical weathering. Physical weathering tends to produce large, angular sediments, which roll down the steep free faces. These sediments, transported almost entirely by gravity, form accumulations called *talus* at the base of the hillslopes.

Because rainfall is infrequent, many of the streams in an arid region are *intermittent*. That is, water flows in them only when it rains, or when snow in higher elevations melts. These streams carry sediments to the intermountain areas, the low areas between hillslopes, where the water dries up and the sediments are deposited. These deposits are likely to include evaporites (see page 348). Thus, the hills are worn down, the hillslopes recede, and the intermountain areas become wider and filled with sediments. The overall result is that the relief of the region becomes less rugged.

Another characteristic of arid landscapes is the sparseness of vegetation. Vegetation performs two important functions in landscape development. The organic matter provided by vegetation is necessary to the development of a mature soil. Of equal importance is the fact that the root systems and surface cover provided by vegetation act to hold the soil in place and thus resist soil erosion by wind and water.

In humid regions, much of the weathering of exposed rock faces is chemical in nature. Chemical weathering tends to produce smoother rock faces than the rough, jagged surfaces characteristic of physical weathering. More important, perhaps, is the fact that most chemical weathering occurs on the rock *surfaces*. As a rock is decomposed by chemical action, its surface often becomes pitted and more easily crumbled. Many of the smaller particles remain in place, forming pockets of thin soil on the hillslope. The adequate moisture makes it possible for grasses and small shrubs to take root and grow in these soil pockets. This vegetation adds to the chemical weathering of the rock beneath. As roots spread, they help hold the soil in place and may also play a role in physical weathering of the rock face.

The abundant rainfall produces permanent stream systems that erode the weathered sediments from the waxing slopes and free faces. These sediments are carried down to lower elevations and deposited, sometimes many kilometers away. The rapid weathering and the erosion by streams combine to reduce elevations and form the rounded hillslopes characteristic of humid regions. In humid regions, the steepness of hillslopes may also be reduced by landslides and slumping, as previously described on page 288. As a result of all these processes, gently rolling landscapes like that in Figure 24-12 on page 472 are produced.

What would happen if the climate in an area changed? It is logical to assume that, if the climate became more humid, landscape features would become more rounded. Similarly, if the climate of a region were to become more arid, and other environmental factors remain unchanged, landscape features would gradually become more angular.

Up to this point, we have been considering the effect of climate on hillslopes. However, hillslopes can also have an effect on climate. In other words, a landscape feature can act as an environmental factor. Suppose, for example, that there is a coastal plain exposed to prevailing winds from the ocean. This region is likely to have a moderately humid climate, as discussed in Chapter 13. Suppose that a crustal disturbance resulted in a chain of mountains being uplifted near the coast. These mountains would present a barrier to the flow of air from the ocean. As explained on page 252, the orographic effect of this mountain barrier would be to force the wind to rise as it moved inland, thus causing the air to cool and to drop more of its moisture on the windward side of the mountains. This loss of moisture, plus the heating of the air by compression as it descends down the leeward side, would produce an arid region on the leeward side of the mountains. Thus, a landscape feature can influence climate.

Stream Patterns. The characteristics of a stream system, as discussed in Chapter 24, are gradient, drainage pattern, and drainage density. As might be expected, the characteristic most influenced by climate is drainage density. Other environmental factors, such as soil or bedrock conditions, can also affect drainage density. The effect of these factors will be considered later in this chapter.

In considering the effects of climate, it should be remembered that it is not just the *amount* of precipitation that determines the type of climate. It is the *ratio* between precipitation and potential evapotranspiration that is important. Where this ratio is large, the climate is humid. There is much surplus water that can run off over the surface or through the ground. Therefore, in a humid climate the surface and subsurface water can support many streams, and we can expect the drainage density to be high. In the two cases illustrated in Figure 24-9 on page 469, we can infer that the climate of region *B* is much more humid than that of region *A*.

Another difference that we would expect to find between the streams in the two different climate regions would be in stream discharge, the *volume* of water that passes a point in the stream in a given amount of time (see Chapter 13, page 243). The discharge pattern of a stream will reflect, to some degree at least, the environment in which the stream exists.

As mentioned earlier (page 489), in arid regions many streams do not flow all of the time. During periods of little or no precipitation, these intermittent streams dry up. At such times, of course, their discharge is zero. During rainy periods, water will flow and the discharge will go up. Thus, the discharge pattern of streams in arid regions may vary from zero during dry spells to maximum values during and

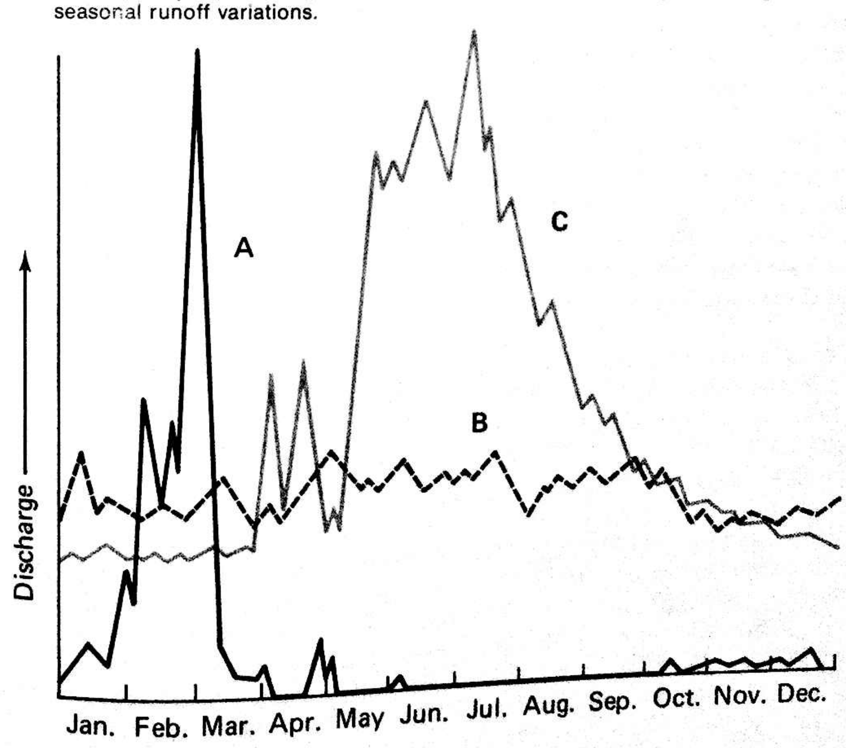
after heavy rains or periods of snow melting. On topographic maps, intermittent streams are shown as broken, rather than solid, blue lines.

The discharge pattern of a stream in a humid region may also show seasonal variation, such as maximum discharge during spring thaw and minimum during a dry autumn. However, discharge rarely, if ever, reaches zero, and the extremes for maximum and minimum values will not be nearly as great as those for intermittent streams of an arid region. Figure 25-14 illustrates the different patterns of stream discharge in arid and humid climates.

Soil Associations. In Chapter 24 (page 470), the importance of soil associations as a landscape characteristic was explained. From the discussion of soil formation in Chapter 14 (pages 279-282), it is clear that climate is the main factor that determines the type of soil that occurs in a region. However, in that discussion, the emphasis was placed on the rainfall aspect of climate. The temperature factor is also important and should be given some further attention.

One of the most important aspects of temperature, as it relates to soil development, is the effect it has on the rate of decay, or decomposition, of organic matter. When a plant or animal dies, its remains consist of complex organic compounds. In order for these compounds to become a useful

Figure 25-12. Patterns of stream discharge in arid and humid climates. (*A*) Stream in arid region of California. (*B*) Stream in humid region of Florida; fairly uniform monthly P/E_p. (*C*) Tributary stream of Missouri River; moderately humid region with seasonal runoff variations.



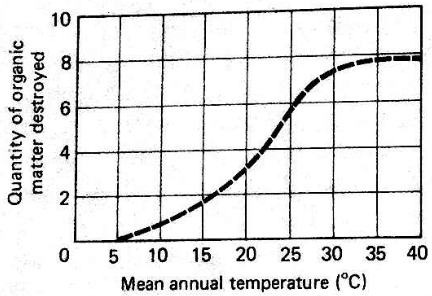
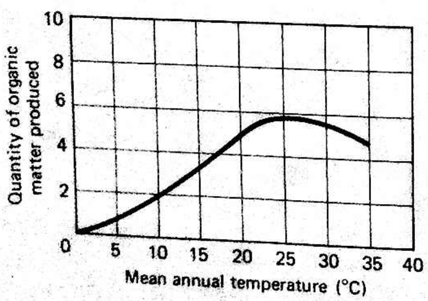


Figure 25-13. Relationship between mean annual temperature and the rate at which organic material is decomposed.

part of the soil for growing plants, they must be partially decomposed. As already mentioned in Chapter 14, partially decomposed organic material in soil is called humus. This decomposition is brought about by the life activities of bacteria. In porous, well-aerated soils, the bacteria are *aerobic*, that is, they use the oxygen in air for their life activities. In poorly drained soils lacking in air spaces, the bacteria present will be *anaerobic*, that is, capable of living without free oxygen.

The rate of bacterial activity is related to temperature. Figure 25-13 is a graph that shows the relationship between the rate at which organic material is completely decomposed by aerobic bacteria and the mean annual

Figure 25-14. Relationship between mean annual temperature and rate of plant growth.



temperature. Plant growth also depends on temperature. As can be seen in Figure 25-14, the rate of plant growth is a maximum when mean annual temperatures are about 25°C. These two graphs are combined in Figure 25-15. We see that below about 25°C, the production of organic material by plants is greater than the rate of complete decomposition by the bacteria. Therefore, in this temperature range, some organic material is only partially decomposed, and humus accumulates in the soil. When average temperatures are greater than 25°C, the bacteria are able to completely decompose organic remains as fast as they are produced. Since completely decomposed material is useless as a soil component, no humus forms under these conditions.

Temperature also plays an important part in soil development on mountains. On high mountains, low temperatures tend to prevent the growth of much plant life, regardless of precipitation. Furthermore, erosion tends to remove weathered rock material as fast as it forms. There is thus little chance for soils of any type to develop. Mountain soils therefore tend to be very thin, with very little development of topsoil and subsoil horizons.

Glacial Action. Another way in which climate affects landscape development is through the action of glaciers. Where climatic conditions are producing glaciers now, or did so in the past, certain definite landscape features appear. In Chapter 15 (pages 301-303), the effects of ice as an erosional agent were discussed. You will recall that one of the chief characteristics of erosion by glaciers is the

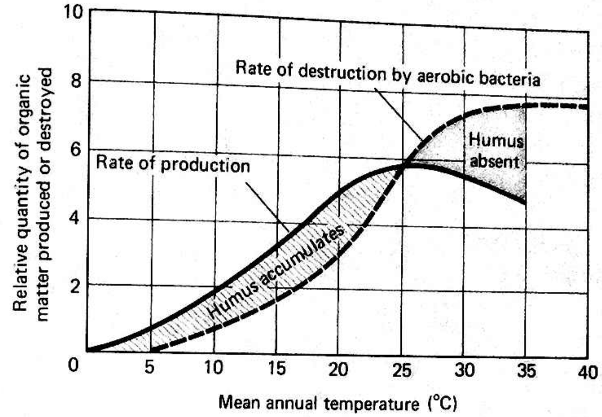


Figure 25-15. Relationship between mean annual temperature and relative rates of production and destruction of organic matter. Where the rate of production is greater than the rate of destruction, humus accumulates. Where the rate of destruction is greater than the rate of production, humus is absent.

formation of U-shaped valleys. In Chapter 16 (page 319), we briefly mentioned the characteristics of deposition by glaciers. In this section, we will examine the effects of glaciers on landscape development in somewhat more detail.

Like shoreline landscapes, landscapes and landscape features produced as a result of glacial activity have special characteristics of their own. As an environmental factor, moving ice would be considered a leveling agent. However, because of the vast amounts of material that can be moved by a glacier, the depositional features of a glaciated landscape are also important. Not only are hillslopes *changed* by glacial action, but some hills are actually *formed* as the result of glacial deposition. Streams are created by glacial melting, and drainage patterns are altered by the erosional and depositional effects of glaciers. Soils are stripped away from some areas and vast amounts of topsoil are deposited in other areas.

There are two classes of glaciers —*alpine* glaciers, which are also called *valley* or *mountain* glaciers, and *continental* glaciers, or *ice sheets*. Alpine glaciers develop wherever mountains are high enough to extend above the snow line. Continental glaciers are huge sheets of ice that cover vast areas of land. Today, thick ice sheets cover most of Greenland and the entire continent of Antarctica. Near the center of the Antarctic ice sheet, ice thicknesses exceed 3000 meters! While the landscapes produced by the moving ice in the two types of glaciers have certain characteristics in common, each has several unique features.

Alpine glaciation. As stated in Chapter 15, alpine glaciers are sometimes called "rivers of ice." The snow and ice collect in basins or depressions high above the snow line. As the snow and ice build up in these basins, the increased pressure causes the ice at the bottom to move, or "flow," as described earlier. Under the influence of gravity, the ice "river" flows

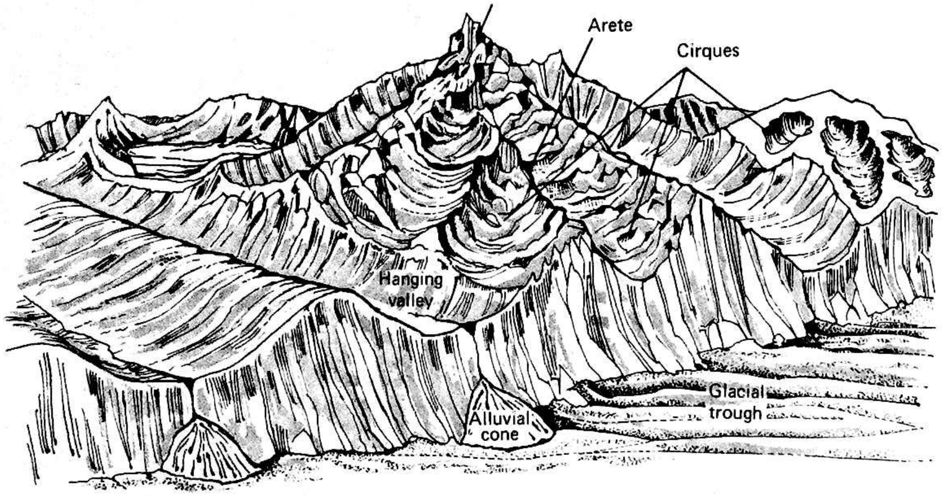


Figure 25-16. Landscape features produced by alpine glaciers.

slowly down the mountainside, gouging and scraping and eroding its valley as it moves. The motion of an alpine glacier is irregular, and the ice at the center moves faster than the ice at the sides. A wide range of speeds have been measured for alpine glaciers, ranging from a few centimeters to a meter or more per day. The leading edge of an alpine glacier reaches its lowest limit at the level where the ice melts as fast as it moves.

Moving ice has the ability to erode all surfaces it touches. As the ice moves, it picks up sediment, much the same as a river does. However, the sediment carried by a glacier includes rocks and boulders in addition to smaller rock and soil particles. As these rocks and rock particles are dragged along by the ice, they scrape and gouge and abrade the bedrock and are an important part of the glacier's erosive power.

In a mountain region where glaciers have not formed, the valleys carved by stream erosion will generally be V-shaped. If the climate then becomes cold enough for glaciers to develop, they may move down these valleys. As a glacier moves through a V-shaped valley, it erodes the valley walls as well as the floor. Most of the waning slopes and debris slopes of the valley walls are removed, leaving only the steep, resistant free face. The result is that the valley cross section is changed to a U shape. (See Figures 25-16 and 25-17.) These U-shaped valleys are called *glacial troughs*.

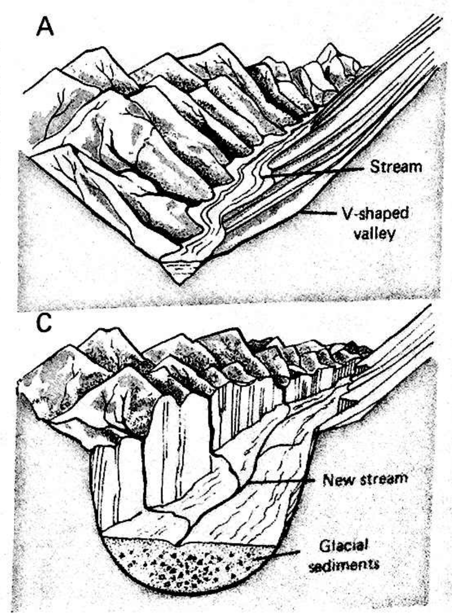
If the climate later becomes warmer again, the glaciers may melt away, and new streams will flow down the center of the troughs. Where tributary ice streams had been, there may be troughs left high on the valley wall of the main glacier. These are called *hanging valleys*. The presence of glacial troughs and hanging valleys in a landscape today is evidence of past glaciation.

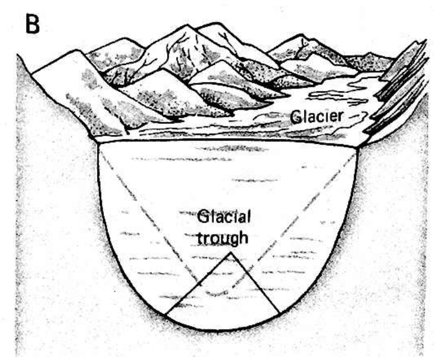
Other landscape features produced by alpine glaciers are found high up on mountain slopes, near the source of the glaciers. The basins or depressions where the snow and ice accumulate become scoured to form amphitheater-like features called *cirques*. When two cirques form in the same region, a sharp, narrow ridge, called an *arete*, is often left standing between them. If glaciation of a mountain is extensive, the peak may be worn away until only a sharp, pyramid-shaped peak called a *horn* remains. All of these features are shown in Figure 25-16.

Thus far, the discussion has focused on erosional features of landscapes influenced by alpine glaciers. Glaciated landscapes also have distinctive depositional features. As glaciers move, they pick up great amounts of rock material, and the particle sizes range from tiny grains to large boulders. All rock material carried by glaciers is called *moraine*, and it is all unsorted—that is, all the sizes are mixed together. The material is carried on, in, under, ahead of, and alongside the moving ice. When the ice stops moving, the moraine stops moving also. If the glacier melts, the moraine is left behind. Various moraine deposits are named according to *where* they were located in relation to the ice. The material that was pushed ahead of the ice marks the farthest limit reached by the ice front. This deposit, called a *terminal moraine*, usually consists of a thick ridge of unsorted material. Other deposits include *ground* moraine, which is a thin, fairly even deposit over the floor occupied by the ice, *lateral* moraine, and *medial* moraine (see Figure 25-18).

Continental glaciation. Large areas of the earth that are presently free of glacial ice have landscapes and landscape features that are characteristic of glacial activity. Therefore, it appears that climatic conditions in these areas were once favorable for the de-

Figure 25-17. Formation of a U-shaped valley. (*A*) V-shaped valley caused by stream erosion. (*B*) As the glacier moves down the valley, it erodes the walls and floor of the valley, giving it a U shape. (*C*) If the climate warms and the glacier recedes, new streams will flow down the middle of the glacial trough.





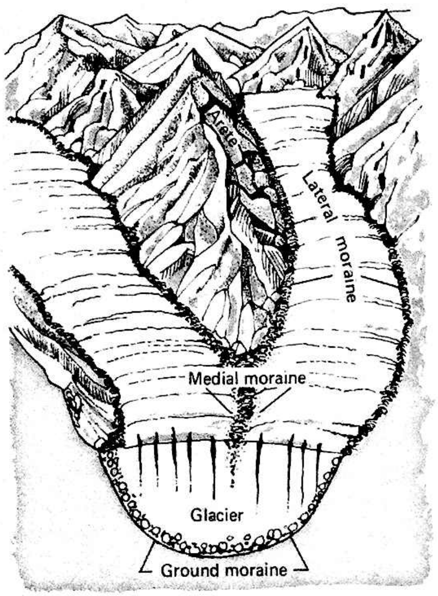


Figure 25-18. Moraine deposits.

velopment of glaciers. In fact, basing their conclusions on evidence from several sources, scientists believe that the climatic conditions in the past were such that the temperate regions of the earth underwent several "ice ages," during which the polar ice advanced and retreated several times. The most recent retreat of ice to its present positions took place sometime between 8000 and 15,000 years ago. Figure 25-19 shows the maximum extent of the glaciation in North America.

Except for the fact that they both consist of moving ice, continental and alpine glaciers have little in common. Alpine glaciers are rather limited in scope, being confined to mountain valleys. The thickness of the ice in these glaciers is measured in tens of meters, and rarely exceeds 100 meters. By contrast, continental glaciers extend over millions of square kilometers of area, and ice thicknesses are measured in thousands of meters.

Figure 25-19. Maximum extent of glaciation in North America. Part of Wisconsin, just south of Lake Superior, was not covered by the ice. This region is called the driftless area.

The movement of ice in a continental glacier is radial. That is, the ice moves outward in all directions from the central part of the glacier, where the ice is thickest. Think about how effective alpine glaciers are in eroding the bedrock over which they move. How much more so the landscape below a great sheet of moving ice must be changed!

In general, the topography of a region eroded by a continental glacier is gentler, or less rugged, than that produced by alpine glaciers. One reason for this fact is that all but the highest of peaks are ground down, abraded, and eroded as the great sheet of ice passes over them. Exposed bedrock in a glaciated landscape has scratches or grooves caused when the rock material carried in the bottom of the ice was dragged over the bedrock.

Many features of a landscape influenced by a continental glacier are depositional. As discussed in Chapter 16, page 319, glacial deposits are of two types, direct and indirect. Direct deposits consist of material left behind when a glacier melts. Indirect, or fluvio-glacial, deposits are carried and deposited by streams of water that flow beneath the glacier or out of the ice front.

Direct deposits consist of unsorted rock material called *till*. Terminal moraines are formed all along the leading edge of the glacier. These moraines may be hundreds of kilometers long, several kilometers wide, and hundreds of kilometers high. The hilly topography of northern Long Island in New York is part of a terminal moraine.

Because indirect deposits are carried by water, they do show some sorting. The largest particles are deposited closest to the ice front and the finer materials are carried farthest from the ice. Broad, fairly flat areas, called *outwash plains*, are often formed ahead of large glaciers.The level, sandy portion of southern Long Island and the prairies of Wisconsin are good examples of outwash plains.

There are several other rather unusual features that are often found associated with glaciated landscapes. *Drumlins* are elongated oval-shaped hills that usually occur in groups or clusters. Drumlins are usually more or less parallel to each other and pointing in the direction of ice movement. Most drumlins consist of unsorted glacial sediments, although some have a solid rock core covered by these sediments. *Eskers* are winding ridges composed of glacial sand and gravel. These ridges form in tunnels beneath the glacial ice, through which streams of water flow. As the ice melts, these tunnels become filled with sediments, which are left behind as eskers. *Kames* are small, cone-shaped hills composed of sand and gravel deposited near the front of a melting glacier. *Kettles* are circular depressions often found on terminal moraines or outwash plains. These depressions form when large blocks of ice break off the glacial front as the glacier is retreating. These large blocks become surrounded by, or covered with, sediments. When the block melts, the kettle is left behind. If the kettle is deep enough to extend below the water table, a kettle lake is formed. Figure 25-20 shows the relationship of the ice and some of the features described above.

Streams and stream patterns are radically affected by continental glaciation. Drainage patterns are altered or interrupted, first by the presence of the ice and later by the deposits left behind. The Finger Lakes of western New York State occupy U-shaped troughs, similar to the troughs formed by alpine glaciers. These troughs were gouged out by the continental glacier in an area previously having a system of stream valleys which ran in a north-south direction.

The actions of glaciers we have described make it very clear that glaciers move enormous amounts of material. Close inspection of soil materials in a glaciated landscape shows that the soils have been transported. They show little resemblance to the parent bedrock of the area.

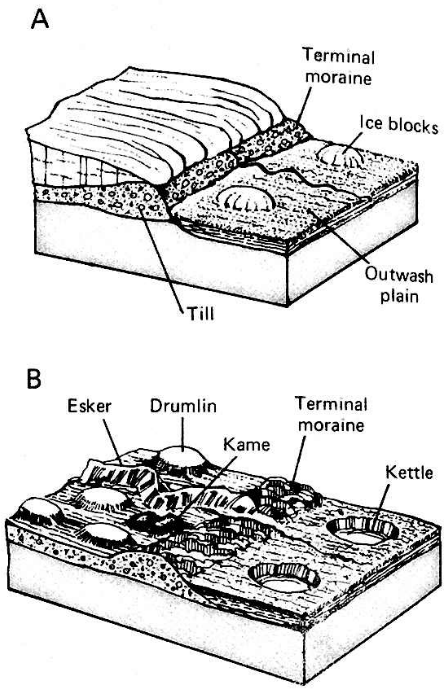


Figure 25-20. Features associated with glaciated landscapes. (*A*) The features before the glacier melts. (*B*) The features after the glacier has melted.

SUMMARY

1. A change in climate, such as from a moist to an arid environment, would result in a modification of the landscape.
2. Some landscapes have characteristics that indicate they developed under conditions of climate extremes, such as glaciation.
3. The rate at which landscape development occurs may be influenced by the climate.
4. The steepness of hillslopes in an area is affected by the balance between weathering and erosion.
5. Other factors being equal, hillslopes that evolved in a dry climate have angular features and prominent free face, while hillslopes that evolved in a humid climate have extensive waning slopes and appear more rounded.
6. Stream characteristics, such as discharge and drainage density, are affected by the climate.

7. Soil characteristics, such as soil depth and type of horizons present, are affected by the climate.
8. There are two classes of glaciers—alpine glaciers and continental glaciers. Because glaciers are able to move vast amounts of rock material, glaciated landscapes are characterized by both erosional features and depositional features.

BEDROCK

It has been noted several times throughout this chapter that the bedrock in a particular region must be considered as a factor that influences the development of the landscape. The reason for this fact should be obvious. The landscape—the physical appearance—of any region is the end result of the sculpting of the bedrock by the processes of weathering and erosion.

Essentially, there are two characteristics that help to determine the role that bedrock will play in the development of the landscape in a given region. One characteristic is the class and/or type of rock that makes up the bedrock of a region. Most nonsedimentary rocks are generally tougher—more resistant to weathering and erosion—than are sedimentary rocks. Also, certain types of rocks are tougher than others of the same class. Limestone, a sedimentary rock, is often more resistant to weathering and erosion than other sedimentary rocks, such as sandstone or shale.

The second characteristic of bedrock is its general "condition." What structural features are present? Has it been deformed by internal pressures? If so, how, and how severely? Has it been tilted, folded, faulted, intruded, or perhaps subjected to a combination of some or all of these deformations? Certain types of rocks are subject to the development of cracks or joints along zones of weakness. All of these characteristics can, and do, have an influence on the landscape that will develop from the weathering and erosion of this bedrock.

As with the other landscape factors, you should keep in mind that bedrock *alone* does not determine landscape. For example, the landscape developed on limestone bedrock in a warm, moist region will probably differ dramatically from the landscape developed on limestone bedrock in a cooler or drier region. It is the interaction of *all* the environmental factors that determines landscape.

In this section, we will take a close look at how bedrock affects the various landscape characteristics.

Hillslopes. The photograph in Figure 25-21 shows a hillslope in Thacher Park, near Albany, New York. This particular hillslope has a prominent feature—a steep-faced bedrock surface, known as a *cliff* or an *escarpment*. The cliff is the free face of this hillslope. Since cliffs are characteristic of many hillslopes, we should know how such features are produced.

On close examination, the cliff face appears to consist of one kind of rock, which seems to be more resistant to weathering and erosion than the rock

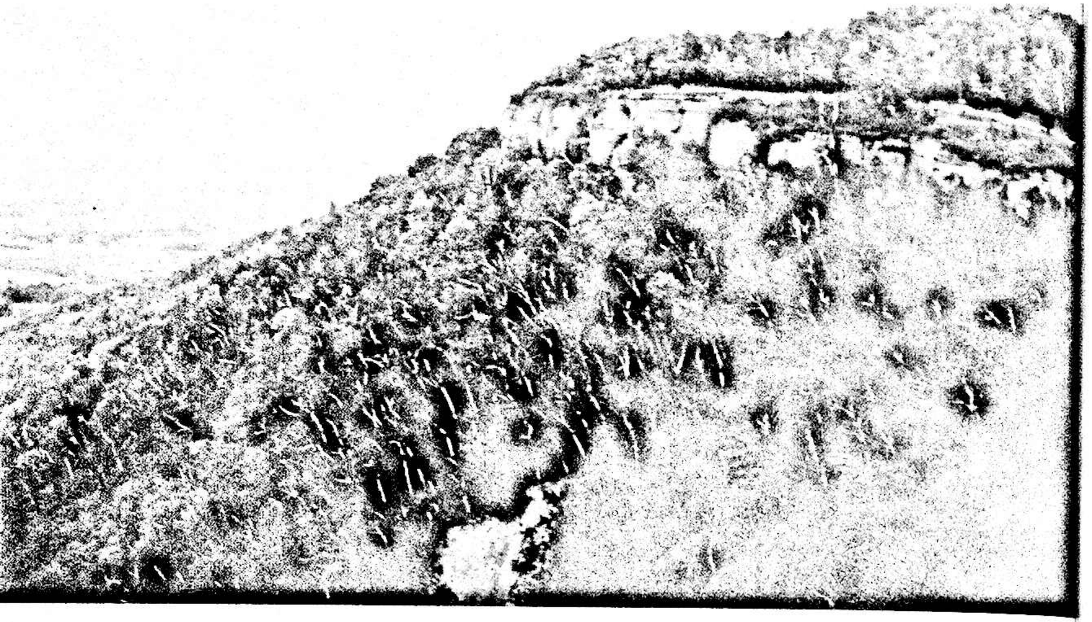


Figure 25-21. Limestone cliff. The limestone of this cliff is more resistant to weathering than the rock below it.

below it. Resistance to the processes of weathering and erosion is called *competence*. A rock that resists these processes is said to be a competent rock. The rock in this particular cliff is limestone. The entire free face is one massive layer of competent limestone. Layers below the free face are composed of shale and limestone, and neither is as competent as the limestone in the cliff. Thus, the weaker, less resistant layers or rock wear away faster than the rock of the cliff. Eventually, the erosion of the weaker layers undermines part of the cliff face, and large blocks of limestone fall away from it. The debris slope is made up of rock material from the weaker rock layers and limestone blocks from the free face.

Figure 25-22 is a cross-sectional drawing of one wall (or hillslope) of the Grand Canyon. Notice that this hillslope, which is almost 2,000 meters in length, shows several cliffs, or escarpments, along its length. Beneath each escarpment is a more gradual debris slope. The same erosional pattern exists here as was seen in Figure 25-21.

Assuming that there are no structural features to consider, the general effect of rock competence on hillslope features can be summed up quite briefly. If all of the exposed bedrock has about the same degree of resistance of weathering and erosion, hillslopes will be fairly uniform and will wear down more or less evenly. If, however, the exposed rocks have different degrees of competence, there will be marked differences in slope between the layers of different resistance, with the most competent layers being steepest.

The diagrams in Figure 25-23 represent two regions where the bedrock has not been deformed by crustal disturbances. The bedrock in diagram *A* is nonsedimentary rock of uniform

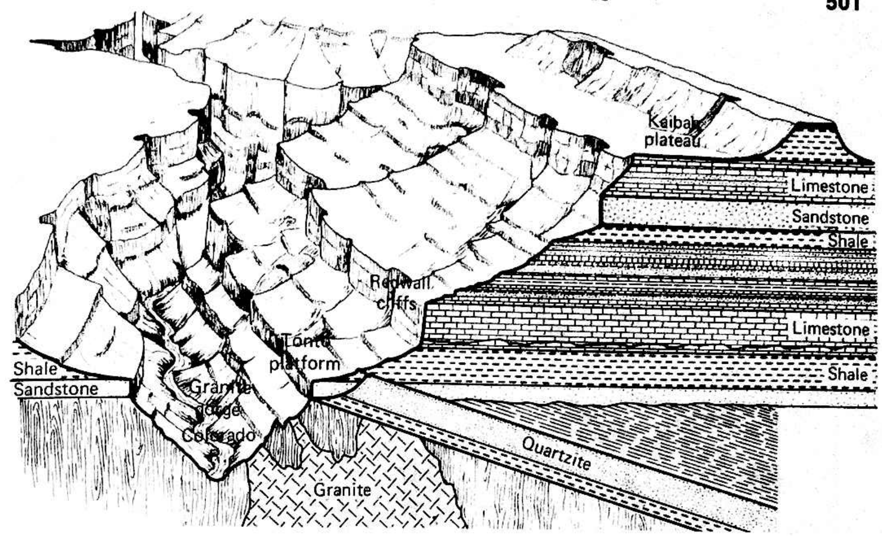
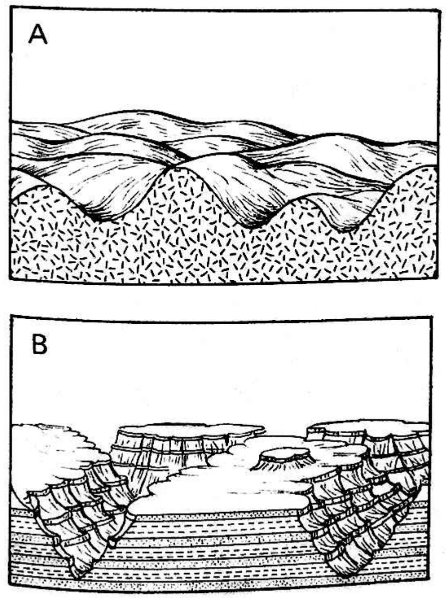


Figure 25-22. Cross section of a wall of the Grand Canyon.

Figure 25-23. Effect of undisturbed bedrock structure on landscape features. (*A*) This region consists of homogeneous nonsedimentary bedrock. The landscape shows a random distribution of rounded hills. (*B*) This region consists of horizontal sedimentary bedrock. The landscape shows generally uniform elevation, with steep-sided valleys cut by streams.



competence. The bedrock of the plateau region in diagram *B* consists of horizontal layers of sedimentary rock of varying degrees of resistance. The differences in the landscape features of the two regions reflect the differences in their bedrock.

The rate at which hillslope features change is also affected by the type of bedrock present. Generally, hills composed of the least resistant rock will be worn down fastest. Those with more competent bedrock should last longer.

As mentioned earlier, structural features of bedrock, such as faults and folds, will also influence the landscape development. The diagrams in Figure 25-24 depict four different situations of bedrock distortion and the possible landscapes that might develop under the influence of the bedrock features.

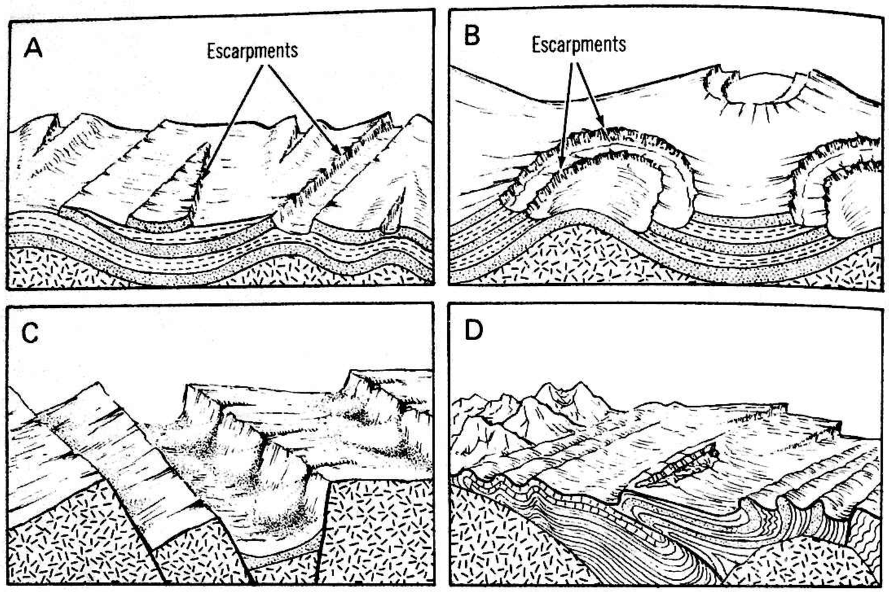


Figure 25-24. Effects of deformed bedrock structure on landscape features. (*A*) With folded strata of varying resistance the landscape consists of roughly parallel ridges, with steep-sided cliffs of resistant rock. (*B*) With a domed structure the landscape features resemble those in (*A*), but ridges and cliffs have a generally circular arrangement. (*C*) With fault-block mountains the landscape features consist of ridges of varying elevation, with steep slopes along the fault planes. (*D*) With a complex bedrock structure the landscape varies greatly in elevation and slope.

Another bedrock feature that can affect landscape is the presence of jointing, especially when combined with faults in the bedrock. Any crack in solid bedrock exposes more of the rock to the processes of weathering and erosion. Stream beds will often follow along an area of weakness such as a fault line. A combination of faulting and jointing in a region tends to result in hills or mountains having a definite "squarish" appearance when viewed from above, as on a map. The Adirondack Mountains in New York State show a definite tendency to this squareness.

Stream Patterns. The stream characteristic most affected by bedrock is drainage pattern. If the underlying bedrock of an area is of uniform composition, there will be no specific regions of weakness along which streams will tend to flow. Thus, streams will develop a random pattern, such as the *dendritic* drainage pattern shown in Figure 24-9A on page 469. There will be few, if any, rapid changes in stream gradient in such a region.

When the bedrock in an area consists of rocks with varying degrees of resistance, or when bedrock features such as folding, faulting, and jointing are present, the drainage patterns will be influenced by these features. The drainage pattern shown in Figure 25-25 is known as *trellis* or *block* drainage. Such drainage patterns are found in regions where the bedrock has been extensively folded and consists of rocks with much difference in resistance to erosion. Trellis drainage is also found in regions of faulted and jointed rock.

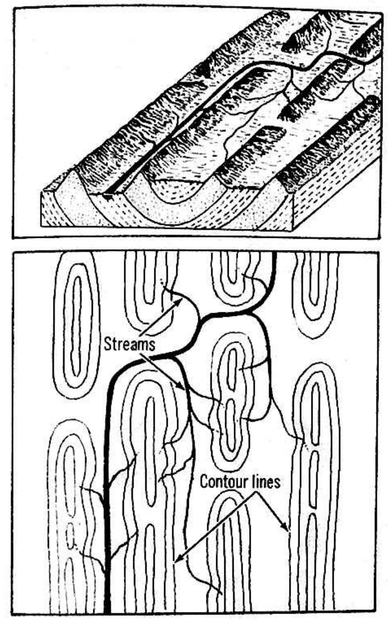


Figure 25-25. Trellis, or block, drainage. This type of drainage is found in folded rocks of differing resistance, and also in faulted or jointed rocks.

The two diagrams in Figure 25-26 illustrate two types of drainage patterns that are found in areas of domed structures. If the bedrock is fairly uniform in resistance, streams will tend to flow in relatively straight courses down the slopes of the dome. The *radial* drainage pattern of these streams is illustrated in diagram *A*. If, however, there are rocks of varying resistance, streams will erode the weaker rocks and tend to follow circular paths around the domes. The annular drainage pattern formed by these streams is shown in diagram *B*.

In regions where there are bedrock features and varying degrees of resistance within the bedrock itself, changes in stream gradient are often present. These changes usually are seen in the form of waterfalls or

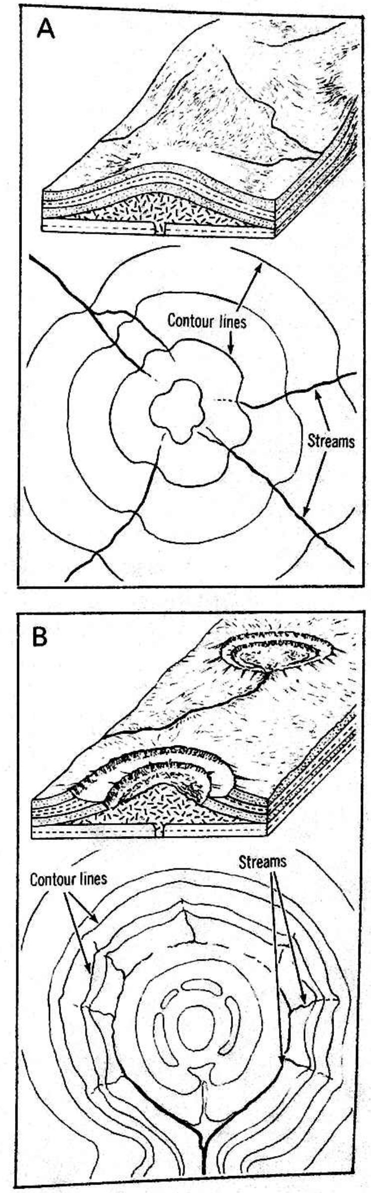


Figure 25-26. Radial and annular drainage patterns. (*A*) Radial drainage patterns occur in areas of domed structure with little difference in rock resistance. (*B*) Annular drainage patterns of concentric circles are found in areas of dome structures with much difference in rock resistance.

rapids. A waterfall is actually a cliff with water flowing over it. Such falls are created where the bedrock beneath a stream changes from erosion-resistant to easily-eroded rock.

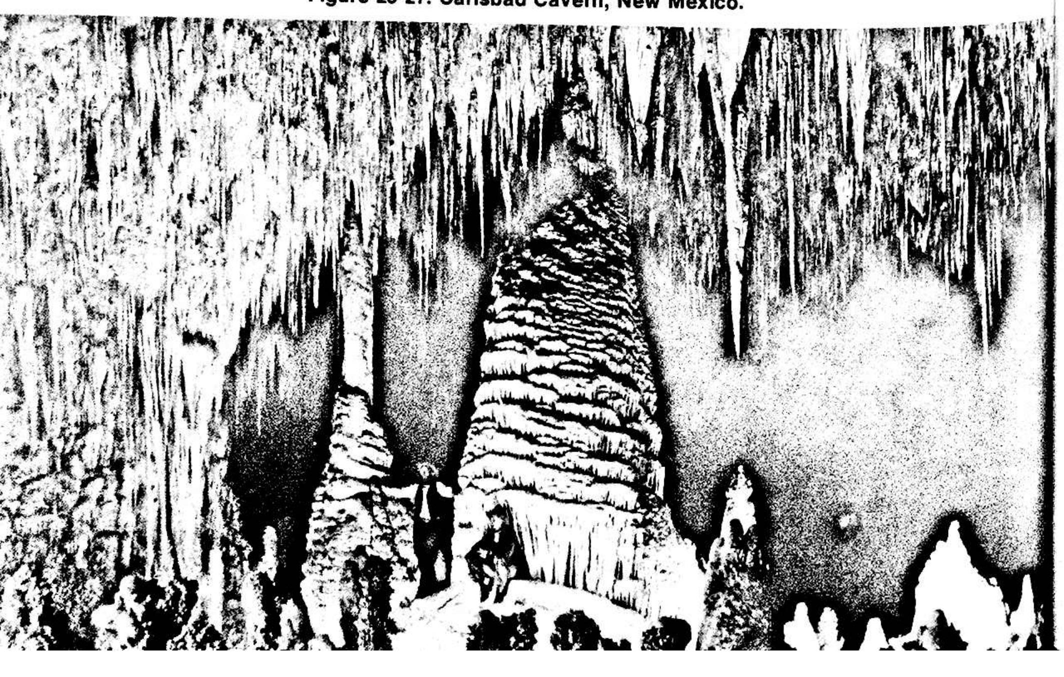
Niagara Falls is a typical example of a waterfall formed because of difference in resistance of rocks in the bedrock (see Figure 15-12, page 297). Upstream of the falls, the river flows over a resistant layer of dolomite limestone. Downstream of the falls, the bedrock is much less resistant to erosion. The lip of the falls marks the edge of the limestone layer. As water flows over the falls, the falling water erodes away the rock beneath the lip, thus undercutting the limestone. As the supporting rock is removed, large pieces of the limestone fall into the gorge. Little by little, the edge of the limestone is being worn back.

In regions that have sufficiently humid climatic conditions, there is one type of bedrock that produces an unusual landscape. The type of rock is limestone. The tendency of limestone to dissolve in groundwater is responsible for producing an *underground* landscape of caverns and streams. The physical appearance of the surface in such a region is known as a *Karst* landscape.

There are few streams on the surface of such a region. Water falling on the surface quickly seeps down through joints and cracks in the bedrock. dissolving more of the rock as it moves downward. Once underground, the groundwater moves through cracks and crevices, dissolving rock material and producing ever larger spaces in the bedrock. Eventually, when the water reaches more resistant rock, it forms underground streams.

The dissolving action of the groundwater forms subterranean caves and caverns, such as the one shown in Figure 25-27. When bedrock

Figure 25-27. Carlsbad Cavern, New Mexico.



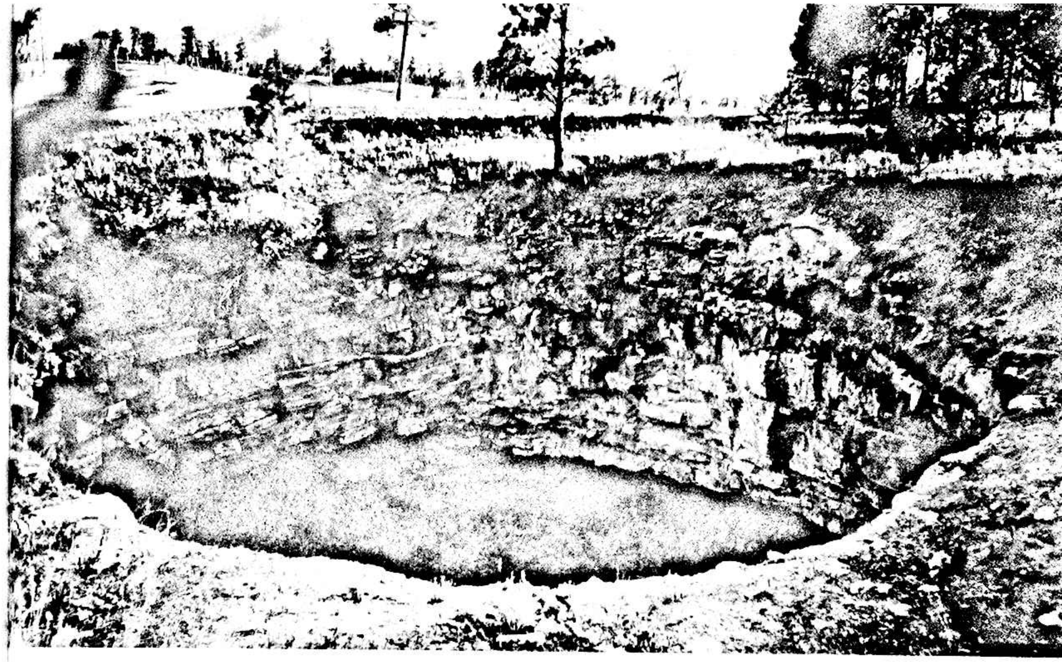


Figure 25-28. Sinkhole in limestone.

near the surface is dissolved, the ceiling of the cavern may collapse to form a roughly circular-shaped *sinkhole* (Figure 25-28). Sinkholes are typical surface features of a Karst landscape.

Soil Formation. Of all the factors affecting soil formation and development, climate has the most influence. However, soils do generally form from the bedrock in a region, and thus the bedrock does play a role in the formation and development of soil.

The composition of a residual soil will reflect the composition of the bedrock from which it forms. Soil formed from granite, for example, will consist of partly weathered quartz, feldspar, and clay (from weathered feldspar), along with bits of mica and hornblende. Another soil, formed from sandstone, will consist mainly of quartz grains, perhaps with some weathered cementing material mixed in.

As a soil develops and becomes older, the material in the upper levels of the soil, farthest from the bedrock. becomes greatly weathered. This weathering, plus the accumulations and decomposition of organic matter, makes it difficult to determine what the parent material might have been. The older the soil, the less it resembles the parent material.

SUMMARY

1. The rate at which landscape development occurs may be affected by the bedrock. The two characteristics of bedrock that most influence landscape development are the type (or class) of rock and the structural features, such as tilting, faulting, and folding.

2. The shape and steepness of hillslopes are affected by the local bedrock composition.
3. Competent, or resistant, rocks are usually found in plateaus, mountains, and escarpments. Weaker, less resistant rocks usually underlie valleys and other low-level areas.
4. Structural features in bedrock, such as faults, folds, and joints, frequently affect the development of hillslopes.
5. Stream characteristics, such as drainage patterns and gradient, are controlled by bedrock characteristics.
6. Soils may differ in composition and are dependent upon the composition of the bedrock. Residual soils resemble the bedrock less as weathering continues. Transported soils may not resemble the bedrock on which they rest.

REVIEW QUESTIONS

Group A

1. What two groups of opposing forces interact to produce landscapes?
2. In any particular interaction, how might the relative influence of the groups of opposing forces be shown?
3. What effect can the rate of crustal uplift or subsidence have on landscapes?
4. On what basis are shorelines classified? What are the three main classes of shorelines?
5. What effect might a change in climate have on the landscape?
6. What inferences can be made from landscape characteristics about the climate conditions under which they formed?
7. What influence might climate exert on landscape development?
8. What characteristic of hillslopes is affected by the balance between weathering and erosion?
9. How do hillslopes which evolved in a dry climate differ in appearance from those which evolved in a humid climate?
10. What two stream characteristics are most affected by climate?
11. What soil characteristics are affected by climate?
12. What are the two classes of glaciers? How is the erosional power of a glacier related to the type of landscape features that are characteristic of most glaciated landscapes?
13. What characteristics of bedrock affect the rate of landscape development?
14. What hillslope characteristics are affected by bedrock composition?
15. What types of landscapes or landscape features are found in regions underlain by competent bedrock?
16. What kinds of structural features in bedrock can influence the development of hillslope?
17. What two factors determine how closely a soil resembles the bedrock on which it rests?

Group B

1. a. The table in Figure 25-1 lists some environmental factors and some landscape characteristics. Which are the causes and which are the effects?
   b. In a certain region constructional forces are greater than destructional forces. What hillslope characteristics would you expect to find there? What stream pattern characteristics? What soil characteristics?
2. a. What hillslope characteristics can be expected in dry climates? In humid climates?
   b. What effect will a humid climate have on erosion?
   c. What kind of drainage density is to be expected in a humid climate?
3. What will be the effect on soils of a high mean annual temperature?
4. How is an alpine glacier different from a continental glacier? What effects do glaciers have on landscapes?
5. a. What will be the shape of hillslopes formed in sedimentary rock if the exposed rock layers are of non-uniform competence? If the exposed rock layers are of uniform competence?
   b. What kind of bedrock conditions will be favorable for the formation of a dendritic drainage pattern? A trellis drainage pattern?
   c. What kind of bedrock conditions would you expect to find in a radial drainage pattern? In an annular drainage pattern?