Hunt Physiography of North Americ

3 The Landforms

General Considerations of Scale and Origin

Hills record at least two quite different chapters of geologic history: one, recorded by the rocks in the hill, involves ancient geologic history; the second is comparatively recent history and concerns the processes and events that caused the hill to be sculptured from those rocks.

These two chapters of earth history may be separated by hundreds of millions of years—a fact that removes some of the mystery about sea shells found on the tops of some mountains. The shells are there not because the mountains were ever submerged but because the rocks containing them were deposited as muds or other sediments in a sea. Subsequently, those sediments became compacted and hardened—*lithified*—by pressure or heat due to their burial beneath younger deposits. Eons later they were raised by earth movements to the altitudes at which we now find them. Still later, erosion carved the mountains from those fossil-bearing rocks.

Landforms and the processes by which they have developed—the subject of *geomorphology*—may be considered on four very different scales (Fig. 3.1). The largest, represented by the continents and the oceanic deeps, have horizontal dimensions measurable in thousands of miles and a vertical relief of more than 10 miles. The processes by which these developed involve the geologic history of the mantle.

The next smaller scale of landforms is that represented by the physiographic provinces, especially on the continents, although the ocean bottoms can be divided into physiographic provinces too. The provinces, whether on the land or under the sea, are characterized by a distinctive kind of geologic structure, and are scores or hundreds of miles wide. Figure 3.1,B, illustrates the structural differences that control landforms in the provinces along the middle Atlantic seaboard.

The next smaller scale of landforms reflects differences in process or position within the physiographic provinces. The differences between valley bottoms, valley sides, and hilltops are examples. Figure 3.1,C, illustrates some landforms in the littoral zone that are attributable to differences in processes operating at various distances from shore. The smallest scale of landforms is measurable in centimeters or inches; every location has its peculiar microrelief, such as mudcracks on the tidal flats, tussock mounds on the sand dunes, and ripple marks where the inshore water is shallow (Fig. 3.1,D).

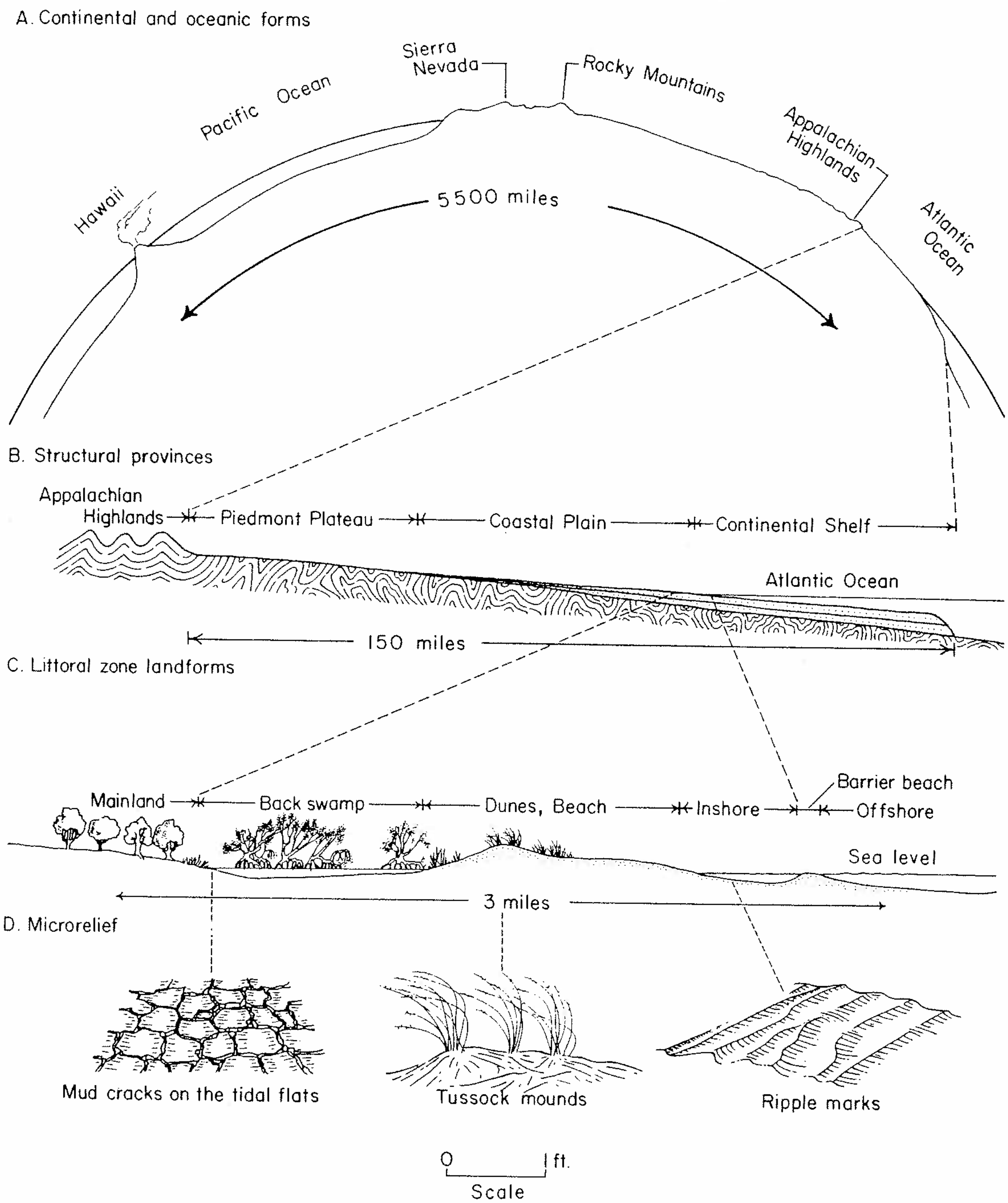

Figure 3.1 *Four scales of landforms. The largest (A) are represented by the continents and the oceanic deeps. Next largest (B) are the physiographic provinces, each characterized by distinctive geologic structure. Within the provinces (C) are smaller differences reflecting different processes. The smallest features (D) are represented in microrelief.*

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The three major factors that control the shape of landforms are structure, process, and stage. In the geomorphic sense of the word, *structure* involves two quite different properties, one pertaining to differences in the resistance of rocks to erosion, the other pertaining to the way the rock formations have been deformed—that is, whether they are tilted, folded, faulted, or have remained horizontal though uplifted. By way of example, landforms developed on folded resistant rocks differ from those developed on similarly folded nonresistant rocks. And these landforms differ from those developed where the formations are horizontal or tilted. The two larger scales of landforms are governed primarily by their structures.

Many different *processes* shape landforms. Some are erosional; others are depositional. The agents of erosion and deposition are streams, waves, glacial ice, and wind, and each process develops distinctive landforms. Valleys eroded by streams tend to have V-shaped cross sections; valleys deepened by glaciers have U-shaped cross sections. Streams build alluvial fans, glacial ice builds terminal moraines, and wind builds dunes. Along the coasts wave erosion and shore currents develop cliffs, stacks, and arches. The coastal outline may be straight, like the east coast of Florida; cuspate between spits, like the coast of North Carolina; or built of great capes, like Cape Cod.

The two smaller scales of landforms illustrated in Figure 3.1 are governed primarily by the processes of erosion and sedimentation that shaped them.

Stage pertains to the duration of a particular process and to its intensity—that is, whether the effects are those of a feeble process, one just beginning to operate, or those of a vigorous process that is well advanced. Stage is merely a modifying factor that controls the shape of landforms; the chief factors are structure and process.

Nevertheless, differences in the forms of stream valleys have been attributed to stage of erosion. Deep narrow valleys and those having roughened gradients have been described by geologists as *youthful.* Valleys that have intermediate width, shape, and longitudinal profile have been described as *mature.* Valleys that are open and have low gradients have been described as *old.* This concept, though, is much over-simplified, for the major differences in landforms result chiefly from structure and, to a lesser extent, process. There is no reason to suppose, for example, that the broad open valleys on top of the Appalachian Plateaus are older than the deeper and narrower valleys of the main streams. A more extreme example is illustrated by some mountains formed by igneous rock, which is resistant to erosion. The surrounding sedimentary rocks erode more readily and their surface is lowered faster, which leaves the mountain of igneous rock higher and usually more rugged. Such mountains appear more youthful as they become older.

There are two other reasons why stage is not very important in shaping the landforms of the provinces. First, most landforms have been evolving throughout the latter part of the Cenozoic Era, a period of many millions of years during which the climates have changed greatly. As a result, the capacity of streams to erode and to transport debris also has changed greatly; episodes of downcutting have alternated with episodes during which streams were unable to cut downward and instead deposited alluvium in their valleys. Second, during the long time that the landforms have been evolving, structural movements have modified stream gradients in many regions and thereby affected their capacity to erode and to transport sediment. In still other regions stream courses have been modified as a result of damming by lava flows.

Figure 3.9,D, illustrates a striking example of differences in landform due directly to change in process (see also Figs. 15.19 and 15.20). A delta, with shore bars and terraces, was deposited at the foot of the Wasatch

Mountains in Lake Bonneville, a Pleistocene lake that was once 1,000 feet deep and lapped against the side of the mountains. Because the climate has changed, the region is now semiarid; Great Salt Lake is the residue of the Pleistocene lake. Stream erosion in the Wasatch Mountains now extends to the foot of the mountains, and the delta and other deposits in Lake Bonneville are now subject to erosion by streams and wind.

Changes in stream regimen and process that are attributable to climatic change also are illustrated by deep, wide glaciated valleys now occupied by streams too small to cut them; an example is Yosemite Valley in the Sierra Nevada. Other changes in stream regimen are illustrated by the alluvial deposits in many western valleys. The deposits and the arroyos they fill record a succession of episodes of downcutting alternating with valley filling.

Much or most of our landscape is the result of processes that have operated during the latter part of the Cenozoic Era. During this time, about 30 million years, there have been earth movements and changes in climates. It follows that most landforms are polygenetic. The landforms evolved while their structure was being changed and while the processes shaping them were changing in intensity or even in kind.

Contrasting the Provinces

Structure

The distribution of the mountains, plateaus, and plains in the United States (Fig. 3.2) reflects the paleogeography of the Paleozoic and Early Mesozoic (Fig. 2.7,A and B) and to a lesser extent that of the Cretaceous (Fig. 2.7, C). The Rocky Mountains formed near the axis of a Cretaceous geosyncline. The Coast Ranges and the Sierra Nevada developed on the sites of Triassic and Jurassic geosynclines. The block mountains in Nevada and the Appalachian Highlands formed along the axes of Paleozoic geosynclines. The plains, both in the interior and along the coast, are the sites of ancient shallow seas (shelf areas) in which thin beds were deposited. In a sense, therefore, the landforms attributed to structure are the product of a series of structures, each dependent upon something that preceded.

PLATEAUS

The four major plateaus in the United States are the Appalachian, Ozark, Colorado, and Columbia plateaus. In each of these physiographic provinces the rock formations are nearly horizontal and the surfaces of the plateaus have been raised high above sea level—2,000 feet in the Appalachian and Ozark plateaus, 1,500 to 4,000 feet in the Columbia Plateau, and more than 5,000 feet in the Colorado Plateau. Parts of the Colorado Plateau—the High Plateaus of Utah—are 11,000 feet above sea level and are among the highest plateaus in the world. Two other plateaus, both averaging below 1,000 feet in altitude, are the Piedmont Province and the Interior Low Plateaus.

A small plateau is known as a butte, or as a *mesa*—a Spanish term commonly used in the Southwest. The difference between a plateau and a butte or mesa is simply one of scale, not unlike the difference between a mountain and a hill.

The geologic structure of a plateau is easy to visualize, and the nearly horizontal but elevated strata can be seen along canyon walls (Fig. 3.3). In the more elevated plateaus the streams are incised deeply, like the Grand Canyon of the Colorado River, or the even deeper, though less colorful, Hell's Canyon of the Snake River along the boundary between Oregon and Idaho. Such canyons have been described as "mountains inside out."

The development of plateaus requires not only the uplift of nearly horizontal formations

Figure 3.2 *Landform map contrasting the physiographic provinces in the United States.*

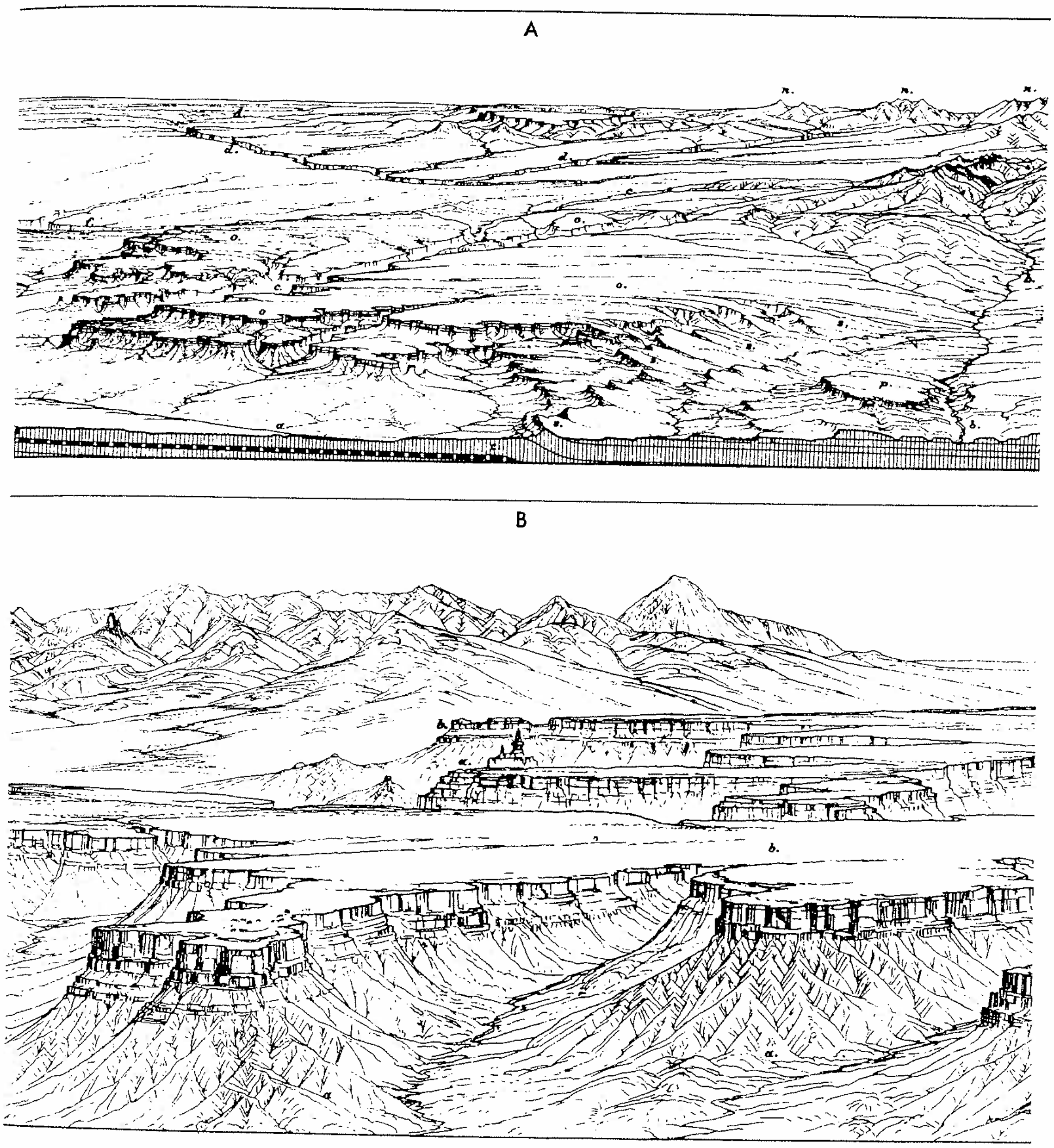

Figure 3.3 *Some plateau structures, as sketched by W. H. Holmes. (A) View north across Mesa Verde* (o) *to the Rio Dolores* (d), *La Plata Mountains* (l), *and San Miguel Mountains* (n) *in southwest Colorado. Other localities: San Juan River* (a), *Rio La Plata* (b), *Rio Mancos* (c), *McElmo Creek* (f), *hogback* (s), *Pinon mesa* (p). *(B) Closer view of the Mesa Verde: slopes* (a) *are shale; the caprock* (b) *is sandstone* (*Cretaceous*).

Figure 3.2 *Landform map contrasting the physiographic provinces in the United States.*

but the presence of resistant formations to maintain the upland surface. In areas where all the formations are easily eroded, the result is badland topography. Similar topography derives from weathering and erosion of homogeneous formations that are resistant enough so that joints, or cracks, in the rock become expressed in the landforms (Fig. 3.4).

Locally in the plateau provinces the formations are flexed into step folds known as *monoclines,* expressed topographically by *hogbacks,* like the one shown at *s* in Figure 3.3,A. Hogbacks, formed by the eroded, protruding edge of a steeply dipping resistant formation, are notable features on the Colorado Plateau, and form some of the spectacular scenery of that area. One, the Waterpocket Fold, is 1,000 to 1,500 feet high and 75 miles long; only at a few places can its rugged cliffs be crossed, even on foot.

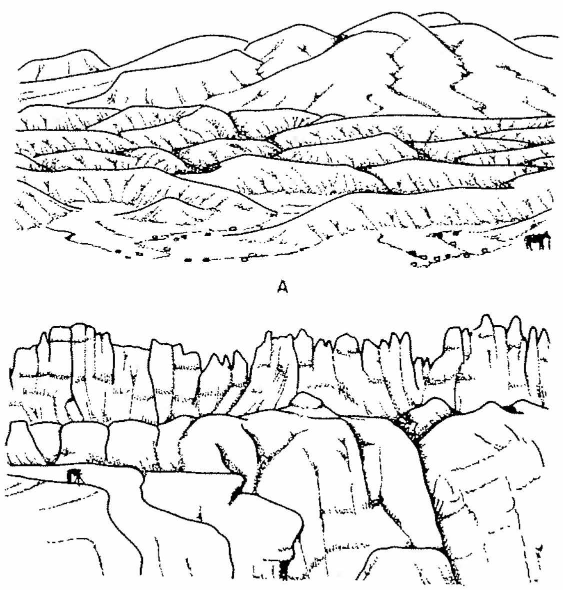

Figure 3.4 *Two kinds of badland topography. (A) Badlands developed in easily eroded, homogeneous Cretaceous shale, Henry Mountains, Utah. (B) Badlands forming The Needles, in Canyonlands National Park, Utah, are developed in Permian sandstone formations. The sandstones are resistant enough so that fractures in the rock* (joints) *become expressed in the topography.*

Where the formations dip less steeply than in a hogback, the resistant formations produce *cuestas,* which are ridges having escarpments facing updip and long, gentle slopes in the downdip direction (Fig. 3.7, section C-D). Cuestas are a characteristic feature of the Coastal Plain Province. They are also characteristic of large areas on the Colorado Plateau and the Great Plains.

PLAINS

Within the United States, there are three major plains (Fig. 3.2). One, the Coastal Plain, is along the Atlantic and Gulf coasts. Another, the largest of them all, comprises the Central Lowland and Great Plains in the Middle West. The third is the California Trough, which forms the Central Valley in California. Another major plain borders the Yukon River in Alaska (Fig. 3.9,C). The Continental Shelf along the Atlantic seaboard is part of the Coastal Plain but is still submerged.

Structurally, plains are like plateaus, for their formations are horizontal, or nearly so, but landforms on plains are less varied than on plateaus because the plains either have not been elevated much above sea level or they rise very gradually from low altitudes, as do the Great Plains, which are higher than the Appalachian Plateaus. Interstream areas on plains are but little higher than the drainage courses, and there is little topographic relief. Consequently, the plains are the most densely populated and most used parts of our land.

A different and special kind of plain is represented by the playas in the valleys separating the block mountains of the Basin and Range Province. Some of these cover thousands of square miles, as does the Great Salt Lake desert, which includes the well-known speed course at the Bonneville Salt Flats. Another large playa, the Carson Sink in Nevada, covers more than a thousand square miles.

There are many smaller ones, such as the salt-encrusted floor of Death Valley, which covers about 200 square miles.

MOUNTAINS

The most complex kinds of landforms are the mountains, which are of many different kinds, each reflecting a different kind of geologic structure. Figure 3.5 illustrates four kinds of mountains—dome, volcanic, fold, and block-fault mountains—and their structures.

Most of the volcanic mountains in the United States are along the Pacific coast, especially in the Cascade Range and Aleutian Islands. These are part of a belt of active volcanoes and numerous earthquake centers surrounding the Pacific Ocean (Fig. 3.6).

Fold mountains, represented by the Valley and Ridge Province in the Appalachian Highlands and the Ouachita Mountains in Oklahoma, have been eroded from sedimentary rock formations that were compressed into great folds; the upturned edges of the resistant formations form the mountain ridges.

A dome mountain is a special and local sort of fold mountain, and consists of a single upfold. The resistant formations turned upward around the dome form concentric ridges between the valleys cut in the more easily eroded formations. Examples of dome mountains are the Adirondacks in New York, the Black Hills in Wyoming and South Dakota, the Zuni Mountains in New Mexico, and the Henry Mountains and San Rafael Swell in Utah.

In the United States the principal area of block mountains, which are formed by faulting, is in the Basin and Range Province. The typical block mountain has an escarpment on the faulted side and a long, comparatively gentle slope away from the fault. The differences in slope on the two sides are illustrated by the profile through the Sierra Nevada (Fig. 2.17), which has been raised along a fault on the east side and tilted downward to the west.

Another important area of block mountains

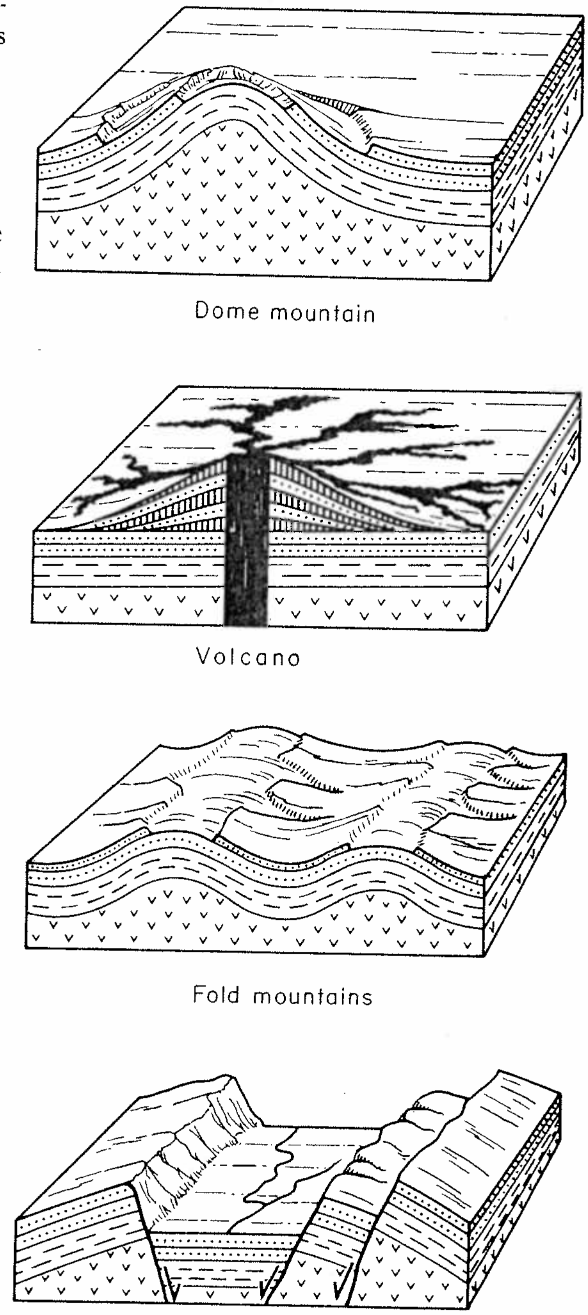

Figure 3.5 *Four kinds of mountains: dome mountain; volcano; fold mountain; block mountain.*

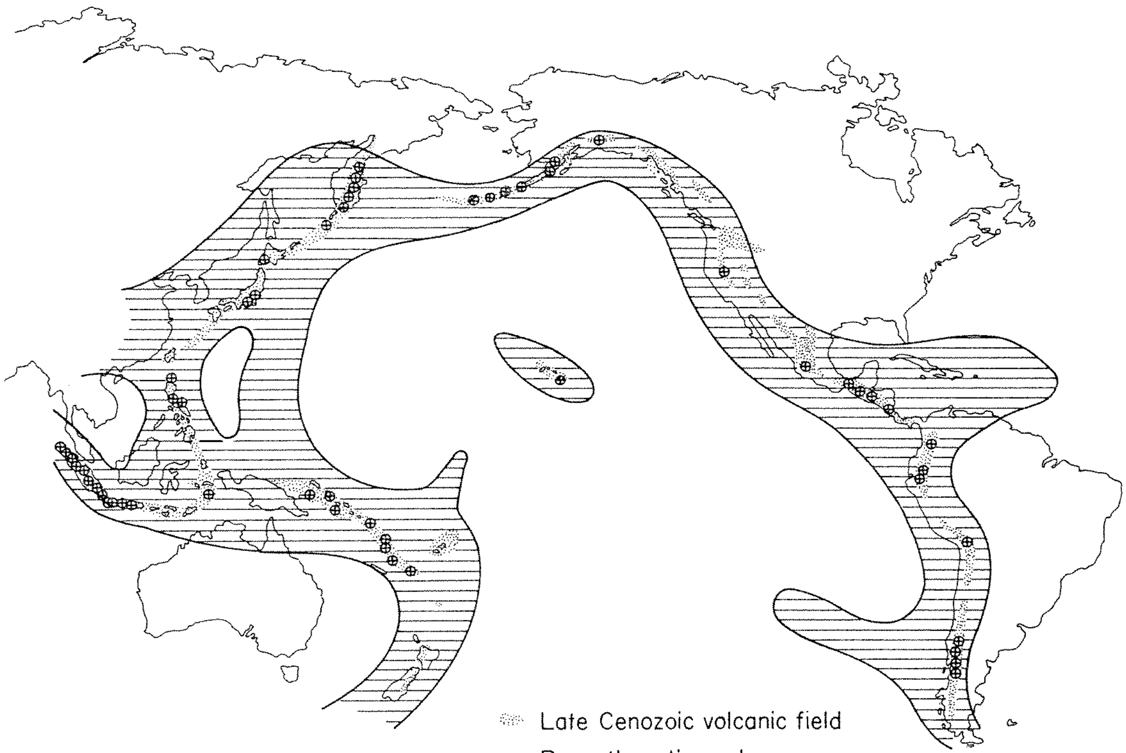

Figure 3.6 *Belt of volcanic and tectonic activity surrounding the Pacific Ocean. Active earth movement is indicated by the frequent earthquakes.*

in this country is the belt of Triassic basins in the eastern part of the United States (Figs. 2.1, 3.7). The Triassic formations, mostly red sandstone and conglomerate with interbedded basalt, occur along the Connecticut Valley and to the south in the Piedmont Province, mostly along its western boundary, from northern New Jersey to North Carolina (Fig. 2.1). In New Jersey, block mountains are represented by the Palisades and Watchung Ridges (Fig. 3.7, section A-B).

Mountains composed of granite develop characteristic landforms. Because granite is both homogeneous and resistant, erosion produces topography not unlike that of badlands, but on a mountainous scale. Granitic mountains are extensive in central Idaho and in the Sierra Nevada, which is a tilted fault block of granite. Smaller granitic masses form the Black Hills, the Highlands of the Hudson, and some mountains in New England. Parts of the Rocky Mountains contain granite, notably the Front Range in Colorado, but the Rockies are complex mountains—partly fold, partly volcanic, and partly granitic.

Drainage Patterns

The structural pattern of a physiographic province becomes etched by stream erosion, and each province has its own characteristic drainage pattern. One type of pattern is branched, like a tree, and is called *dendritic.*

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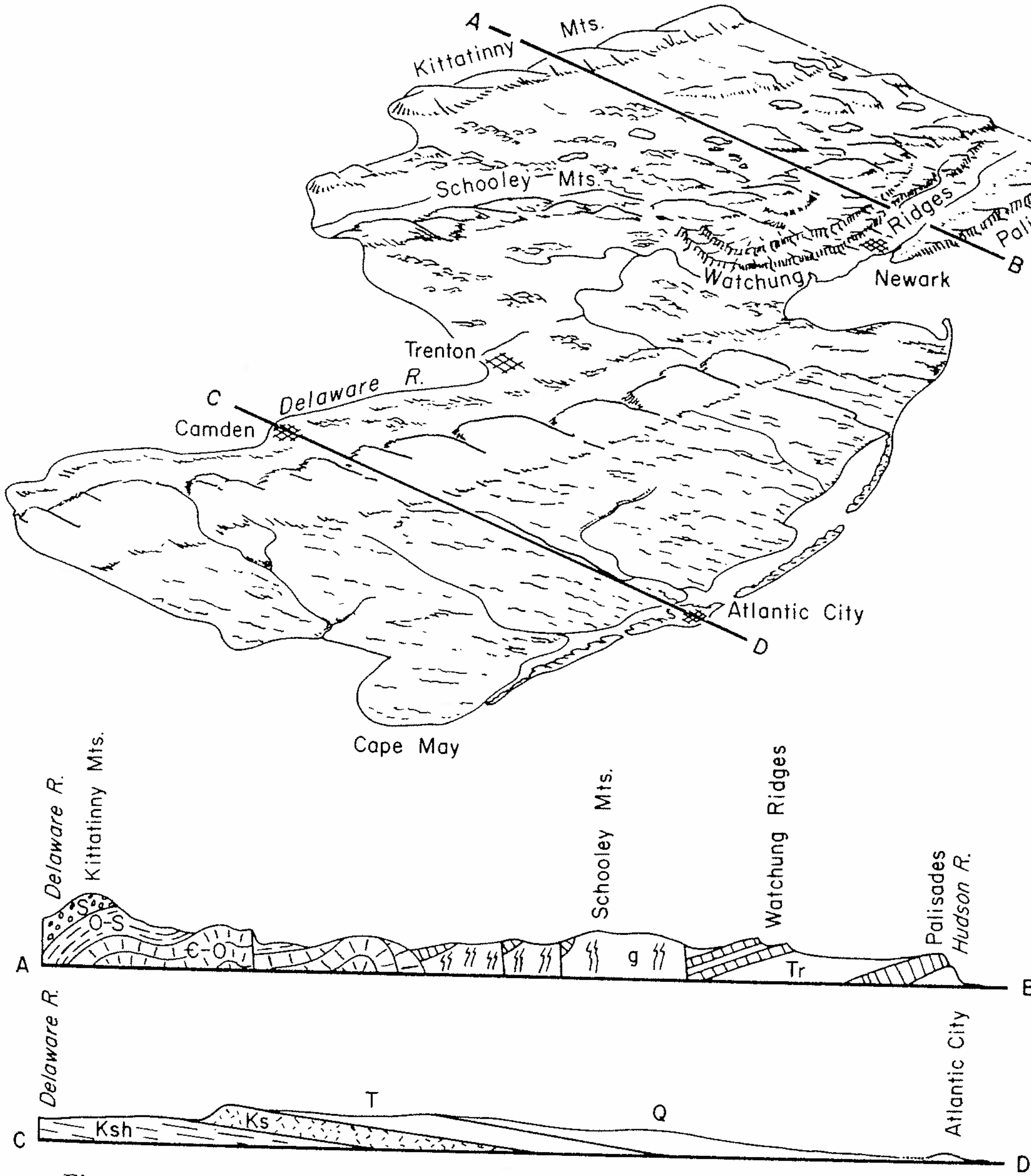

Figure 3.7 *Relief map and cross sections of New Jersey, illustrating several kinds of landforms. Southeastern New Jersey is coastal plain with Cretaceous* (K), *Tertiary* (T), *and Quaternary* (Q) *formations dipping gently seaward. The resistant formations form ridges (cuestas) paralleling the coast. The New Jersey turnpike follows one of the westernmost valleys. Atlantic City is on a barrier beach. The Triassic* (Tr) *belt of block mountains extends from Newark Bay to Trenton and westward to the Reading Prong, which is a complex* (g) *of granite, volcanic rocks and Paleozoic formations. To the west are the folded Cambrian* (€), *Ordovician* (O), *and Silurian* (S) *formations.*

Drainage systems in plateaus are likely to have this pattern. Examples are the Columbia and Snake rivers on the Columbia Plateaus and the Colorado River on the Colorado Plateau (Fig. 5.1). On plains the drainage pattern tends to be *parallel* in the direction of slope, as on the Coastal Plain and on the Great Plains (Fig. 5.1). Parallel drainage also has developed on the long western slope of the Sierra Nevada. Where the geologic structure consists of long parallel folds or faults, the drainage pattern is like a *trellis,* with long straight stretches parallel to the structures and short stretches at right angles across them, as in the Valley and Ridge Province and in the Coast Ranges of California. In isolated mountains, like the Adirondacks and the volcanoes of the Cascade Range, the drainage is *radial.* In the Southern Rocky Mountains the drainage is radial, though on a larger scale.

Although these several kinds of drainage patterns reflect the geologic structure, the history of the drainage courses is highly complex, partly because of changes in climate, partly because of stream diversions such as might be caused by glaciation, and partly because of earth movements. An example of such complexity is illustrated by the riddle of how major rivers have developed and maintained their courses across mountain ranges instead of around them. Examples are legion; seven well-known ones are:

1. Columbia River gorge through the Cascade Range (Figs. 17.11, 17.14).
2. Golden Gate, San Francisco Bay (p. 387).
3. Gorge of the Bighorn River across the Bighorn Mountains, Wyoming-Montana (p. 271).
4. Colorado River gorges at the Black Mountains, Arizona and Nevada, Uncompaghre uplift, and White River Plateau, Colorado (p. 271).
5. Royal Gorge of the Arkansas River, Colorado (Fig. 13.1, p. 270).
6. Delaware River at the Water Gap (Fig. 11.22,A).
7. Susquehanna River at Harrisburg (Fig. 11.22,B).

These features can be attributed to any of three kinds of origin, referred to as *antecedence, superposition,* or a combination of those two that has been termed *anteconsequence* (or *anteposition*) (Fig. 3.8). The process of antecedence involves uplift of a potential barrier across a drainage course at a rate slower than the rate of downcutting by the stream, thus allowing the stream course to be maintained (Fig. 3.8,A). Superposition involves development of a drainage course on a surface that covers older formations that may be folded, and when the stream cuts downward into the older rocks, the drainage course becomes superimposed on those structures. Such streams bear no relation to the buried rock structures and cut across them (Fig. 3.8,B). The processes are combined where uplift ponds the drainage, which overflows the barrier; the effect is that of antecedence downstream from the barrier and superposition upstream from it (Fig. 3.8,C).

Landforms Attributable to Deposition

The converse of erosion is sedimentation, and the conditions that favor erosion, if reversed, favor deposition of sediments. Depositional landforms may be produced by the same agents that produce the erosional ones—that is, by streams, glaciers, waves, or wind. The depositional landforms are as varied as the erosional ones, but in general they are less extensive; many are merely local.

Depositional environments are of three major kinds: (1) *continental environments*—glaciers, streams, lakes, marshes, and dunes; (2) *marine environments*—shallow seas and deep seas; and (3) *mixed continental and marine environments*—the littoral zone, tidal lagoons, estuaries, and deltas. The deposits in each of these kinds of environments have characteristic bedding. Glacial till lacks bedding.

Stream deposits, including the glaciofluvial ones included in glacial drift, are stratified, but the beds are discontinuous because of frequent changes in the stream position. Lake deposits and marine deposits are, in general, thin-bedded, and individual beds may persist for long distances.

Among the stream-deposited features are floodplains, deltas, alluvial fans, and talus aprons (Fig. 3.9). Most large rivers have floodplains, even though many are narrow; along many streams there are terraces recording old floodplains at high levels. Three large floodplains in the United States are those along the Mississippi River, in the central valley of California, and along the lower Yukon and Kuskokwim rivers in Alaska (Fig. 3.9,A, B, and C). Some deltas that are well exposed for study are in the now dry bed of Lake Bonneville (Fig. 3.9,D). Alluvial fans may be steep and small (Fig. 3.9,E) or may be gently sloping and large, covering many square miles. Other kinds of deposits include *talus,* which collects at the foot of steep slopes as a result of rock falls (Fig. 3.9,F), and *colluvium* (Fig. 3.9,G), which collects on hillsides and moves slowly down gentle slopes—a process called creep.

Glacial deposits cover most of the northern United States (Fig. 6.1) and occur on the high mountains in the western United States and even in Hawaii. A few examples of the many different landforms built by glacial deposits are illustrated in Fig. 3.10.

At the front, or terminus, of a glacier, gravel and sand are deposited to form a hummocky ridge called a *terminal moraine* (Fig. 11.16). Such ridges extend across valleys that were occupied by mountain glaciers, and many contain lakes. Terminal moraines also formed around the fronts of the lobes of the continental ice sheets. Examples of these are the concentric ridges around the south end of Lake Michigan and around the ends of Lake Erie and Saginaw Bay (Figs. 3.10 and 12.2).

Beyond the terminal moraines are *outwash plains* of sand and gravel deposited by meltwaters from the ice (Fig. 11.16). These plains

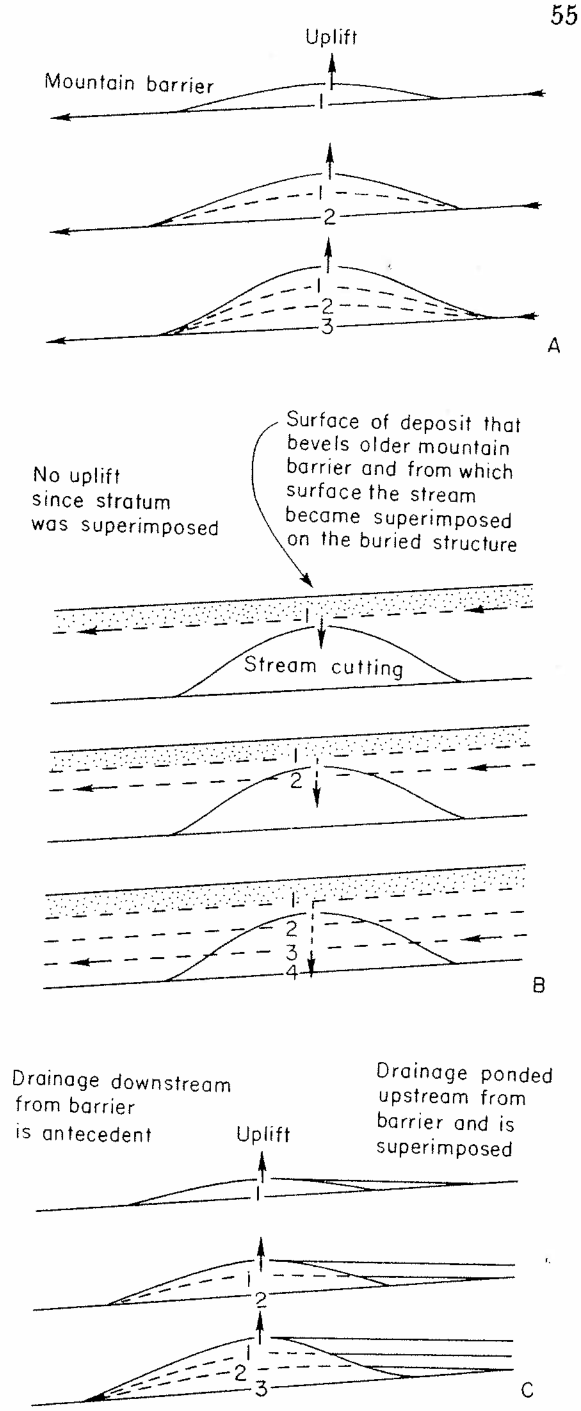

Figure 3.8 *(A) Antecedence. (B) Superposition. (C) Anteconsequence. Broken lines represent positions of former drainage after being raised structurally, from 1 (oldest) to 4 (youngest).*

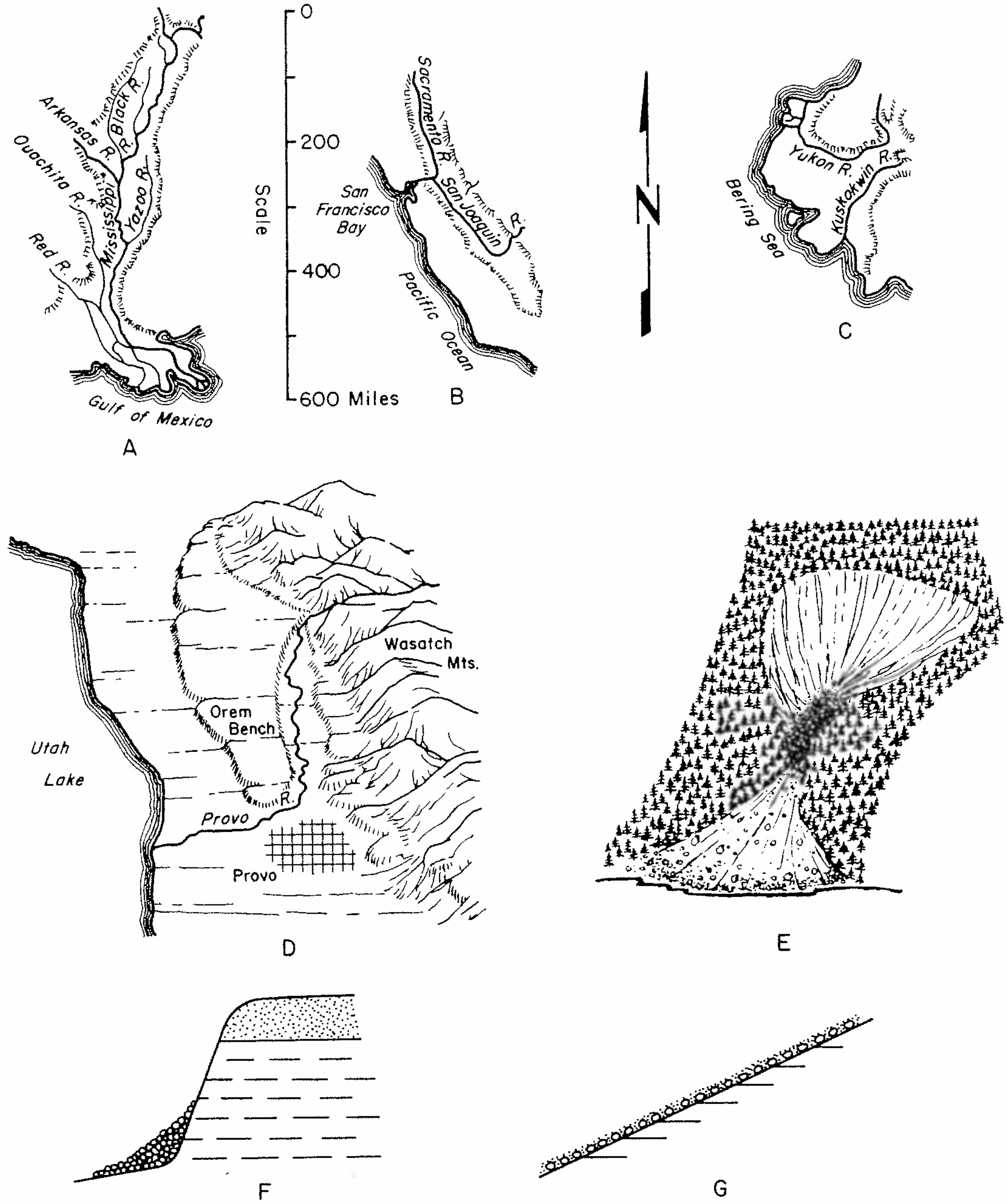

Figure 3.9 *Some depositional landforms. Floodplains of (A) Mississippi River; (B) Sacramento and San Joaquin Rivers, California; (C) Yukon and Kuskokwim Rivers, Alaska. (D) Delta of Pleistocene Lake Bonneville forms Orem Bench near Provo, Utah, at the foot of the Wasatch Mountains. (E) Alluvial fan, Rocky Mountains, Colorado. (F) Talus at the foot of a cliff, a gravity rather than a stream deposit. (G) Colluvium on a hillside.*

and the moraines are hummocky, partly because deposition was torrential and irregular, and partly because blocks of ice were deposited with the sediments. When these blocks melted, depressions formed, which are known as *kettle holes;* the hillocks are referred to as *kames* (Fig. 3.10,B). Ice readvancing over the hillocks would reshape them like teardrops (*drumlins*), elongating and tapering them in the direction of the ice readvance (Fig. 3.10,C, 11.15,A, 11.17). Many of the hills about Boston, including Bunker Hill, are drumlins.

Still another example of landforms attributable to deposition by glaciers are ridges (*eskers*) formed by the channel gravels of streams flowing on or under the glacier. When the ice melted, the channel gravels of these streams were deposited as meandering ridges that join where the glacial streams joined (Fig. 3.10,D).

Other depositional landforms besides glaciers are attributable to deposition by waves, such as barrier beaches and beach bars (Figs. 3.1, 3.7, 10.5, 10.6), spits, capes, and hooks (Figs. 3.7, 10.21).

Depositional features attributable to wind include dunes and loess plains. Dunes may be arcuate or elongate and parallel. Some arcuate dunes are concave in the windward direction, others are concave to the leeward. The elongate dunes are parallel to the wind direction. The kind of dune depends partly on the availability of sand, strength of wind, and presence of vegetation, which collects and holds the sand. Loess—wind deposited silt—blankets the middle western plains (Fig. 6.1) and forms the rich soil of that area. The loess dates from the glacial periods and originated as dust blown eastward out of the great river valleys, where it was deposited by floods caused by melting of glacial ice.

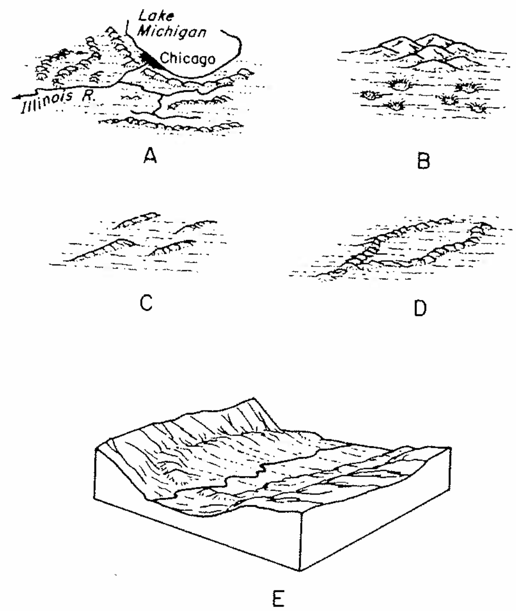

Figure 3.10 *Landforms attributable to deposition by glaciers. (A) Terminal moraines south of Lake Michigan form a series of concentric ridges separated by till plains, outwash plains, and lake beds. (B) Kames and kettle holes on a till plain. (C) Drumlins. (D) Eskers. (E) Lateral and terminal moraines deposited by a former valley glacier.*

Finally, to complete the list of depositional features, some are built by organisms: coral reefs, beaver ponds, peat marshes, gopher mounds, buffalo wallows, and ant hills.