CHAPTER 11
LANDSCAPES

1. INTRODUCTION

1.1 A course on the environment of the Earth's surface would be seriously incomplete without a chapter on the Earth's landscapes. An early chapter dealt with practical matters of describing the lay of the land by means of topographic maps. Now is the time to give attention to nature and origin of the Earth's landforms and landscapes.

1.2 Everybody knows about landscapes. Dictionaries define a ***landscape*** as *the aggregate of surface topographic features in some region as produced or modified by geologic processes*, or as *a region of the Earth's surface that the eye can see in a single view*. A ***landform*** is *some topographic feature of the Earth's surface that originated by natural processes*. You can think of a landscape as consisting of a number of individual landforms, of various kinds, in some definite relationship one to another. Hills, mountains, and valleys—of which there are many kinds—are examples of landforms. You have already learned much about specific landforms, in the earlier chapters on rivers and glaciers. Now is the time to have a more systematic look at the Earth's major landforms.

1.3 The study of landforms is a matter dealt with in the science of ***geomorphology*** (the study of the Earth's landscapes and the processes that shape them), a branch of Earth science that has been around since early in the modern age of Earth science, in the nineteenth century. Geomorphologists view themselves in part as geologists and in part as geographers. In the US, geomorphologists have tended to be geologists, whereas in the British sphere they have tended to be geographers. (Turf distinctions, although to a large extent artificial, have always been with science, as is true of many other fields as well.)

1.4 There is a longstanding dichotomy in geomorphology between the study of the history of development of landscapes, on the one hand, and the study of natural processes that shape the Earth's surface. The latter is usually referred to as "process geomorphology", and has been alive and well in recent decades. We have done quite a lot of it in this course. The former, however, which was first systematically developed by the preeminent early geomorphologist William Morris Davis (1850–1934) has had a checkered history.

1.5 The plan of this chapter is first to deal with classical Davisian geomorphology, along with some alternatives, and then to look at some of the prominent landscape elements that develop in areas of the Earth's surface—and they constitute much the greater part of the Earth's surface—where fluvial processes dominate. First, however, the following section presents some initial material on mountains and valleys.

2. MOUNTAINS AND VALLEYS

2.1 Just to get you started thinking about the Earth's prominent landforms (there will be more detail later in the chapter), here are some comments about the nature of mountains and valleys.

2.2 As you will see soon, mountains are diverse not only in their scale and geometry but also in their processes of origin. I suppose that if you were to ask the proverbial "person in the street" about how mountains originate, he or she would tell you that they are somehow "built" to stand above their surroundings. There are indeed such ***"constructional" mountains*** (an only semi-official term), as the next few paragraphs describe.

2.3 Volcanic mountains, especially, come readily to mind as constructional mountains. Volcanoes emit lava (liquid, melted rock) and solid particles of a great variety of compositions and sizes. Much of this material is deposited in the vicinity of the fissure or vent, to build a hill or a mountain.

2.4 Volcanoes that emit basaltic lava, of relatively low viscosity, build mountains that are very broad, with gentle slopes. Such volcanoes are called ***shield volcanoes***. The great volcanoes of Hawaii and the Galápagos Islands are shield volcanoes. In a certain sense, Kilauea, on the big island of Hawaii, is the world's tallest mountain—if you measure the vertical distance from its base, in the deep ocean, to its summit!

2.5 Many volcanoes emit solid particles rather than liquid lava. Eruptions from such volcanoes tend to be explosive—often catastrophically so. The volcanic ash erupted from the volcano is thrown high into the atmosphere, and much of it settles to the ground over large areas, but some is deposited in the immediate vicinity of the volcano, to build a classic cone-shaped mountain. Such volcanoes are called ***cone volcanoes***. Mount Fuji, in Japan, is a classic cone volcano. Many such volcanoes consist of alternations of layers of lava and ash. The slopes of cone volcanoes are generally much steeper than those of shield volcanoes.

2.6 Mountains are also constructed by movements on faults. (A ***fault*** is *a widespread fracture in bedrock along which the material on the two sides of the fracture have moved relative to one another*.) Fault movements that have a vertical component to the movement create topography. Movements of major faults or fault zones can create great mountain ranges. Figure 11-1 shows a common example. The fault surface, usually approximately a plane, is inclined at a steep angle. The movement is such that the mass of rock overlying the fault surface moves downward relative to the mass of rock underlying the fault surface. The result is a mountain range with an adjacent valley. There are many such mountain ranges in the large area in the southwestern U.S. called the ***basin-and-range province***. Death Valley is a classic example: the main fault (called the "range-bounding fault") is on the east side of the valley; it is inclined to the west (or, in the parlance of geology, it *dips* to the west) at a moderate angle. The range of mountains east of Death Valley is going up, and the valley is going down, as a result of episodic movement on the fault. Of course, as the mountain goes up it is at the same time being worn down by erosion. The sedimentary products of the erosion are being deposited in the valley. The fill of the valley has attained a thickness of thousands of meters.

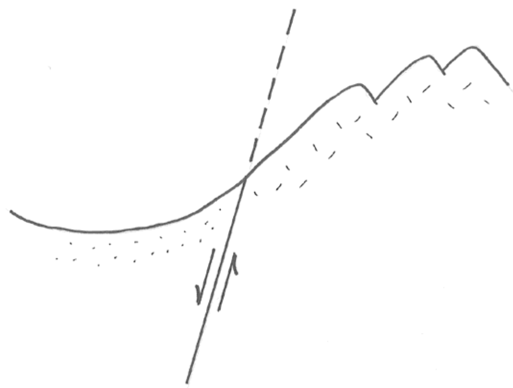


Figure 11-1. A mountain range and a valley formed by movement on a fault.

2.7 It may seem counterintuitive to you at this point, but you will learn in this chapter that most of the Earth's mountains are ***"erosional" mountains*** rather than constructional mountains. Such mountains come about by broad uplift, over a large area of the Earth's crust, and then erosion by streams and rivers, to leave elevated remnants of the originally uplifted area as mountains, surrounded by lowlands and valleys.

2.8 The central Appalachians of the eastern U.S., in Pennsylvania for example, are an excellent place to study erosional mountains. In much earlier geologic times the entire area was broadly uplifted by several hundred meters. Since then, erosion has excavated valleys, leaving higher ground, underlain by the rocks most resistant to erosion, as mountain ridges. The process has been most advanced in the eastern part of the area; westward, into northwestern Pennsylvania, the progress of erosion has been less advanced, and there is an extensive plateau, called the Allegheny Plateau, that is cut here and there by deep stream valleys.

2.9 You can see now that some valleys are produced by fault movements, and are usually occupied by streams and rivers, except in arid regions, whereas other valleys are the result of downcutting into broadly uplifted regions by streams and rivers.

3. DAVISIAN GEOMORPHOLOGY

3.1 Early on, toward the end of the nineteenth century and into the early part of the twentieth century, an explanatory account of the development of landscapes was developed by application of a deductive approach: observe a large number of existing landscapes and then try to arrange them into a "movie" that represents the development of landscapes through time. Essential to this endeavor, of course, is a good understanding of the processes that shape landscapes in the first place. The problem is that just because such a movies can be made does not mean that that's how things work!

3.2 As the decades of the twentieth century passed, to a considerable extent this approach fell out of favor. In more recent times, however, with the advent of modern ideas about tectonism, brought about by the emergence of the plate-tectonics paradigm, along with development of better techniques of dating rocks and even surfaces, there has been a resurgence of interest in the historical aspect of landscapes.

3.3 In Davis's time it was generally believed that orogeny (the building of mountainous terrain by tectonic activity) tended to occur as brief pulses, worldwide, and then, in the long time periods in between, there was tectonic quiescence while the land was gradually worn down. It was natural, then, for Davis to assume rapid broad uplift of a large region of the Earth's continental crust and then slow reduction of elevations over very long periods of time. Davis concentrated on what is actually just a subset of the Earth's land areas: those with substantial rainfall and well-developed river systems that mobilize and transport the products of weathering to the oceans. That leaves out vast arid and semiarid regions of the Earth's surface, where differing geomorphic processes tend to leave rather different landscapes.

3.4 Davis perceived a cycle: rapid uplift, long-term quiescence while the landscape was worn down, then renewed rapid uplift. That cycle has been called the *humid geomorphic cycle*, or the *humid cycle of erosion*. It has been a central aspect in geomorphic thinking, but it has been controversial from early on, and its problems caused it to fall into disfavor by the mid-twentieth century. The elements of reality that it carries, however, has kept it alive in geomorphologists' thinking, albeit with reservations. An account of it here seems therefore to be warranted.

3.5 A key element in Davis's thinking was the ***peneplain***: a broad low-lying region, hundreds if not thousands of kilometers across, that is the ultimate stage in the cycle. A peneplain ("almost a plain") is not nearly a planar surface: it slopes gently upward from the ocean shoreline, nowhere attaining elevations greater than some hundreds of meters, and it has subdued hill-and-valley topography. One big problem with concept of a peneplain is that, even though it makes perfectly good deductive sense, it's difficult to identify any peneplains in today's world! (Such a problem has a natural tendency to turn scientists off from an otherwise attractive concept.) You can view the Davisian cycle of erosion as uplift of a preexisting peneplain, progressive dissection of that peneplain, and eventual development of a new peneplain. But the big question is: does it ever really work that way?

3.6 Davis viewed his humid erosion cycle in terms of broad, qualitative stages, with no well-defined boundaries and with no specification of actual ages in years: **youth**, **maturity**, and **old age**, by loose analogy with the life histories of organisms.

3.7 After initial uplift (Figure 11-2A), in the stage of ***youth*** (Figure 11-2B), streams are rapidly incising into the newly uplifted surface. Most of the area consists of low-relief uplands, called ***interfluves***, between the active stream channels. Valley slopes are steep, and valley profiles are V-shaped. In ***maturity*** (Figure 11-2C), headward development of stream channels has mostly eliminated non-dissected interfluves. Stream valleys have widened, valley slopes have become gentler, and overall relief of the region is declining. In ***old age*** (Figure 11-2D), the region has been worn down to an even lower elevation, relief is much reduced, streams are of low gradient, and divides are broad and low. The region is close to being a peneplain.

3.8 But does it ever really happen this way? You could make it happen, on a very small scale, on a large stream table or a backyard erosion plot. The trouble is that scale models of that kind, although often very revealing, are only qualitative: they are not dynamically similar (to use a term from fluid dynamics), in the sense that all forces, motions, and processes are in the same proportion in the model as in the natural case. Scientific common sense, tells us, however, that something akin to the humid geomorphic cycle must be applicable to large continental regions, provided that there is rapid uplift and then long-term tectonic quiescence.

3.9 It's clear these days that tectonism (movements of the Earth's crust) is not nearly as well-behavedly episodic as the early geomorphologists believed. It's clear that in regions of plate convergence (ocean–continent subduction, as in the Andes, and continent–continent collision, as in the Himalayas–Tibetan Plateau region of southern Asia), strong regional uplift can last for tens of millions of years, and, all the while, streams are denuding the landscape—a far cry from the Davisian concept of rapid uplift followed by long quiescence. Even in such regions, however, now-uplifted remnants of the old, preexisting low-relief and low-elevation surface can persist for geologically long times. In fairness to Davis, I might point out here that he himself emphasized that interruptions to his cycle of erosion must be common and important.

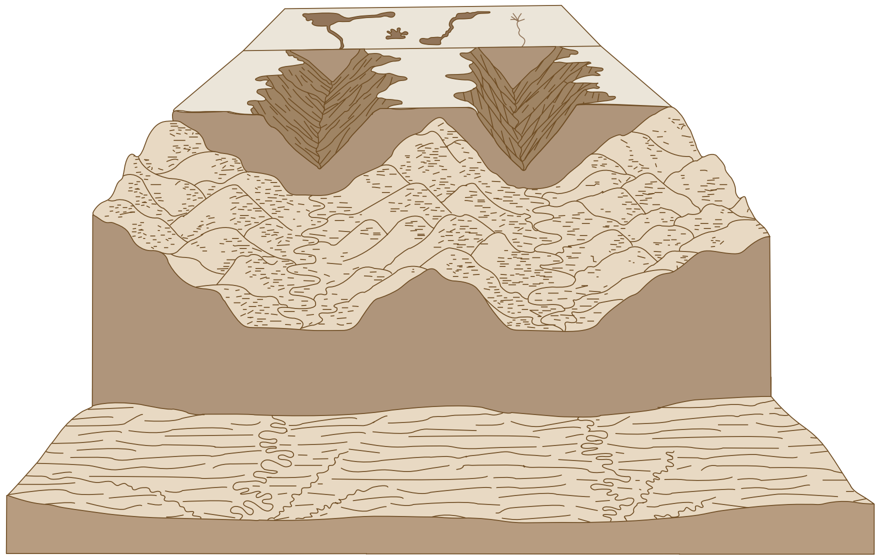
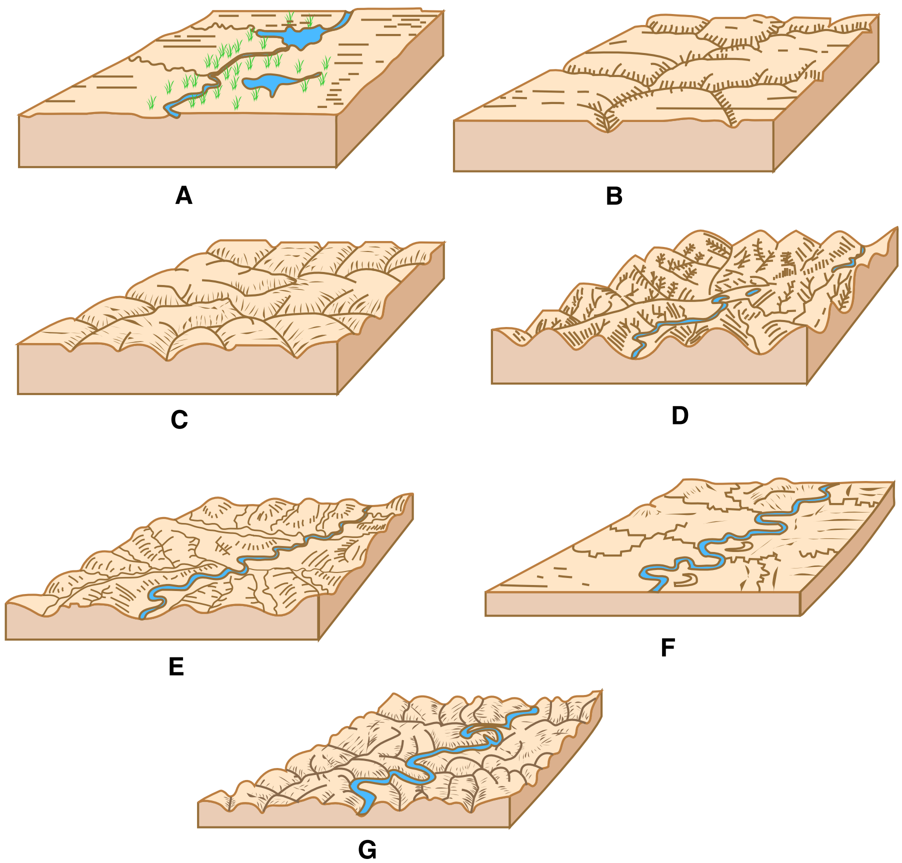


Figure by MIT OCW

Figure 11-2, Part 1. Stages in the humid geomorphic cycle. A) Initial stage; B) youth; C) maturity; D) old age. (From Easterbrook, 1999).

3.10 A key concept in the humid erosion cycle is ***accordance of summits***. Someday, when you are traveling southwest from New England on Interstate Route 84 through southern New York State toward northeastern Pennsylvania, take a brief detour south into northwestern New Jersey. (There's a convenient exit labeled "Mountain Road", the last before the road reaches Port Jervis, where the three states of New York, New Jersey, and Pennsylvania come together.) Along a ridge of the Appalachians in northwestern New Jersey, at the highest point in the state, is a Washington Monument–like structure upon an almost treeless and spectacularly three-hundred-and-sixty-degree observation site. There you can let your eye sweep around the compass at the surrounding landscape, near and far. The striking thing about that vista is that to an excellent approximation one can fit to all of the distant mountain summits on the horizon a single plane, one that rises gently from east to west. The summits are in the form of ridges consisting of resistant rock units, all trending approximately parallel in a northeast–southeast orientation governed by the underlying bedrock structure of the Appalachian orogen. The intervening valleys are underlain by weaker rock, where streams have eroded the landscape to much lower levels. The inference is attractive to the point of being overwhelming that such topography is the result of uplift of a low-lying plain and then fluvial incision to exploit zones of weak rock while leaving the more resistant rock almost unaffected as divides between the various streams (Figure 11-3). Does that mean that the land was uplifted in a single episode, and



The cycle of land-mass denudation in a humid climate. (After E. Raisz.) A, in the initial stage, relief is slight, drainage poor. B, In early youth, stream valleys are narrow, uplands broad and flat. C, In late youth, valley slopes predominate but some interstream uplands remain. D, In maturity, the region consists of valley slopes and narrow divides. E, In late maturity, relief is subdued, valley floors broad. F, In the old stage, peneplain with monadnocks is formed. G, Uplift of the region brings on a rejuvenation, or second cycle of denudation, shown here to have reached early maturity.

Figure by MIT OCW

Figure 11-2, Part 2. Stages in the humid geomorphic cycle. (From Strahler, 1975.)

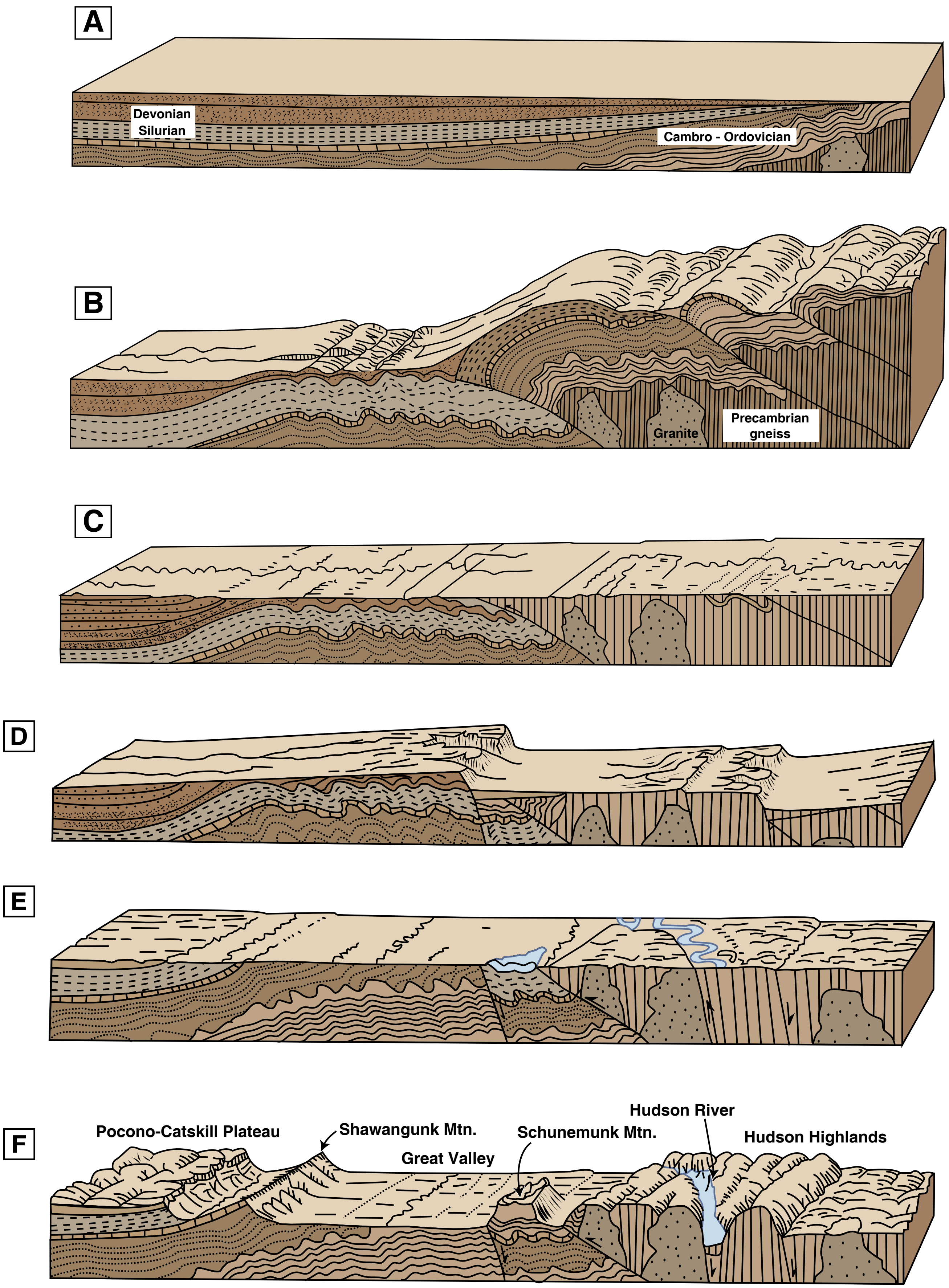


Figure by MIT OCW

Figure 11-3 (previous page). Uplift and dissection of a preexisting peneplain, to form the present topography of the central Appalachians. (From Strahler, 1975.)

then remained high while erosion proceeded, in the Davisian way? Not necessarily: perhaps uplift has been ongoing, concurrently with denudation. In either case, it's difficult to avoid the deduction that there once was a low-lying plain that got uplifted and eroded!

4. HOW FAST ARE THE CONTINENTS WORN DOWN?

4.1 Geomorphologists use the term ***denudation*** for *the overall, regional lowering of a continental land surface by processes of weathering, erosion, and transportation of bedrock material to the oceans*. Rivers, of course, are by far the most important agents of denudation, although ice sheets have been very effective at certain times and places in geologic history.

4.2 For a long time, geoscientists have been trying to develop estimates of rates of denudation. There are several ways of doing this—none of them perfect.

Measuring the sediment load of rivers. Because almost all of the products of denudation are carried by rivers, it should seem natural to you to measure the sediment loads of all of the word's rivers to get a yearly total of the sediment delivered to the oceans, and then imagine that volume to be spread over the area of the continents to get an annualized denudation rate. Many such estimates have been made. There are some serious problems, however. One is that it's notoriously difficult to measure the sediment load of rivers, especially bed load. Moreover, systematic measurements of the total load (suspended load, bed load, and dissolved load) are common on relatively few rivers around the world. A broader problem is: *how representative is last year's sediment load, say, of denudation on time scales of millions of years?* It's generally agreed that humankind has greatly accelerated denudation, owing largely to agriculture. And then there's the matter of natural fluctuations in climate, on scales ranging from centuries to millions of years. Despite all of that pessimistic commentary, however, here are some figures. Worldwide estimates are in the range of several centimeters per millennium, but values range widely, from just a few centimeters per millennium, for tectonically stable regions without high relief, to far higher values, even up to a few meters per millennium, in tectonically active areas with high relief and abundant rainfall (a widely cited example is the eastern mountains of Taiwan).

Deposition rates in the ocean. The obvious alternative to measuring the sediment loads of rivers is to estimate the volume of sediment that has been deposited in the oceans over some period of geologic time. Most of the solids load of rivers is deposited along the continental margins (but dissolved load is not easily taken into account in this way). Geophysical methods of measuring sediment thickness, together with coring to define the stratigraphy, lead to regional estimates of denudation. The advantage of this method is that it should provide estimates of denudation over geologically long times and also show changes in rates through time. Estimates for the eastern seaboard of North America are a few centimeters per millennium, in the same ballpark as estimates made on the basis of sediment loads of rivers.

Rates of erosion of land areas. If the thickness of continental rocks removed in some interval of geologic time can be measured or estimated, that gives the most direct indication of denudation rates. In some places it has been possible to make a direct measurement—for example, where a basalt flow of known age covered a preexisting land surface and then has been removed along with some thickness of the underlying material. In many regions, study of metamorphic facies and thermal history has led to estimates of the thickness of rock unroofed owing to long-continued uplift, especially in orogenic regions. Again, rates vary widely but are generally in the range of a few centimeters per millennium to a few tens of centimeters per millennium.

4.3 A striking conclusion from data of the kind noted above is that, given denudation rates even of just a few centimeters per millennium, which seems to be a conservative estimate, a continent like North America would be worn down to low-lying terrain in geologically short times, of the order of ten million years! Just divide the average elevation of North America, of the order of five hundred meters (5×10^5 cm), by a denudation rate of, say, five centimeters per millennium (5×10^{-3} cm/yr). The result: ten million years. Why, then, are all of the continents not just low-lying plains? (One factor is that rates slow way down as elevation and relief decrease.) We are forced to appeal to *long-continued uplift*: orogenic, in the case of uplift of mountain ranges, which is relatively rapid and relative restricted in area, or epeirogenic, which is relatively slow but covering relatively large areas. (The adjective *orogenic* is used to describe building of mountains in a local region; the adjective *epeirogenic*, less easy to grasp, is used to describe broad vertical movements that affect large parts of a continent.)

3.4 That leads to the issue of the competition between uplift rates and denudation rates. You might think in terms of the two end-member cases:

• **Uplift rates are much greater than denudation rates**. This would be the case in an tectonically active but arid region with rapid uplift of the crust: the land is coming up fast, but rainfall to weather the rock and remove the weathering products is scarce. The maximum elevation in such an area would then be controlled by rock strength. There seems to be a self-limiting process at work here: when the uplifted mass becomes sufficiently high, it literally flows out sideways, at depth, on a regional scale of many hundreds of kilometers, by a complex of tectonic processes we need not deal with here, thus limiting the maximum elevation. That seems to be happening in the Altiplano, in the Andes, and in the Tibetan plateau, in southern Asia.

• **Denudation rates are as great as uplift rates.** Owing to high rainfall in a humid climate conducive to rapid rock weathering, denudation rates can keep up with even very high rates of uplift, limiting mountain elevations to just a few thousand meters despite the very rapid uplift. One of the classic areas of that kind is the eastern mountains of Taiwan.

4. DRAINAGE DEVELOPMENT IN NEWLY EMERGENT REGIONS

4.1 Now for some more concrete and closer-to-home stuff for you. First, here's some background on the recent geologic history of the Eastern Seaboard of North America (see Figure 11-4). Like other passive continental margins (those facing an expanding ocean with a mid-ocean spreading ridge in the middle, and no strong tectonism caused by plate interactions along the continental margin), the east coast of North America underwent long-continued slow subsidence, caused by thermal contraction of the cooling lithosphere as it moved away from the ridge crest. A seaward-thickening wedge of siliciclastic sediment was deposited along the continental margin, dating back to not long after the breakup of Pangea, about two hundred million years ago. It's also known, however, that in more recent times, in the past few tens of millions of years, there has been general, broad uplift of the continental margin of North America, for unclear reasons. (That's known from study of the stratigraphy of the offshore sediment wedge.) The present coastal lands of the Eastern Seaboard have a landward-thinning veneer of almost flat-lying marine deposits, called the ***coastal plain***. The coastal-plain wedge laps up onto much older rock with generally complex structure generated during the Appalachian Orogeny, which led up to the assembly of Pangea. The Eastern Seaboard has thus been undergoing erosion for many millions of years, and in the process the thickness of coastal-plain sediments has been reduced and their western edge has retreated eastward, exposing more and more of the older rocks.

4.2 Got the picture? Now think about the development of river drainage during the uplift of the past few tens of millions of years. As the continental-shelf sediments are gradually exposed to form a widening coastal plain, a new pattern of drainage becomes established on the gently sloping sedimentary cover. It's natural to assume that the streams and rivers flow down the slope, generally toward the southeast in most areas. Such streams are called ***consequent streams***—because they are consequent upon emergence of the region above sea level. These streams, and their tributaries, gradually denude the region as they extend headward and lower their profiles. If the sedimentary cover of the coastal plain is uniform, the drainage pattern is likely to be dendritic (see the chapter on rivers).

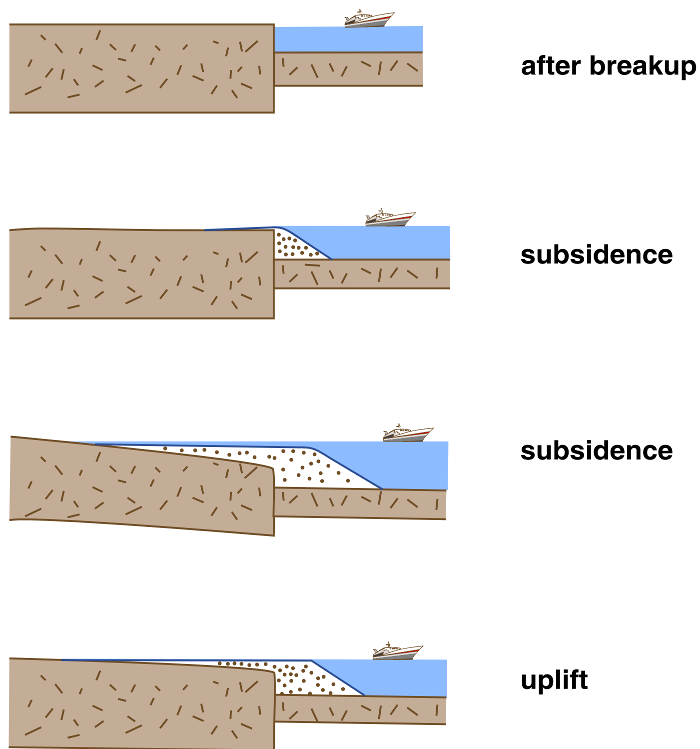


Figure by MIT OCW

Figure 11-4. Recent geologic history of the Eastern Seaboard of North America.

4.3 Eventually, the rivers and streams lower their courses to the point where they encounter the "basement" rock underlying the coastal-plain sediments. At that point, certain tributaries to the larger consequent streams encounter belts of weaker rock, and their courses become adjusted to follow those belts of weaker rock. Such streams are called ***subsequent streams***. The orientations of the subsequent streams can vary widely, but in a region like the Eastern Seaboard of the US, where the structural trend of the older rocks underlying the coastal-plain strata is generally parallel to the shoreline, the subsequent streams tend to be perpendicular to the consequent streams (Figure 11-5).

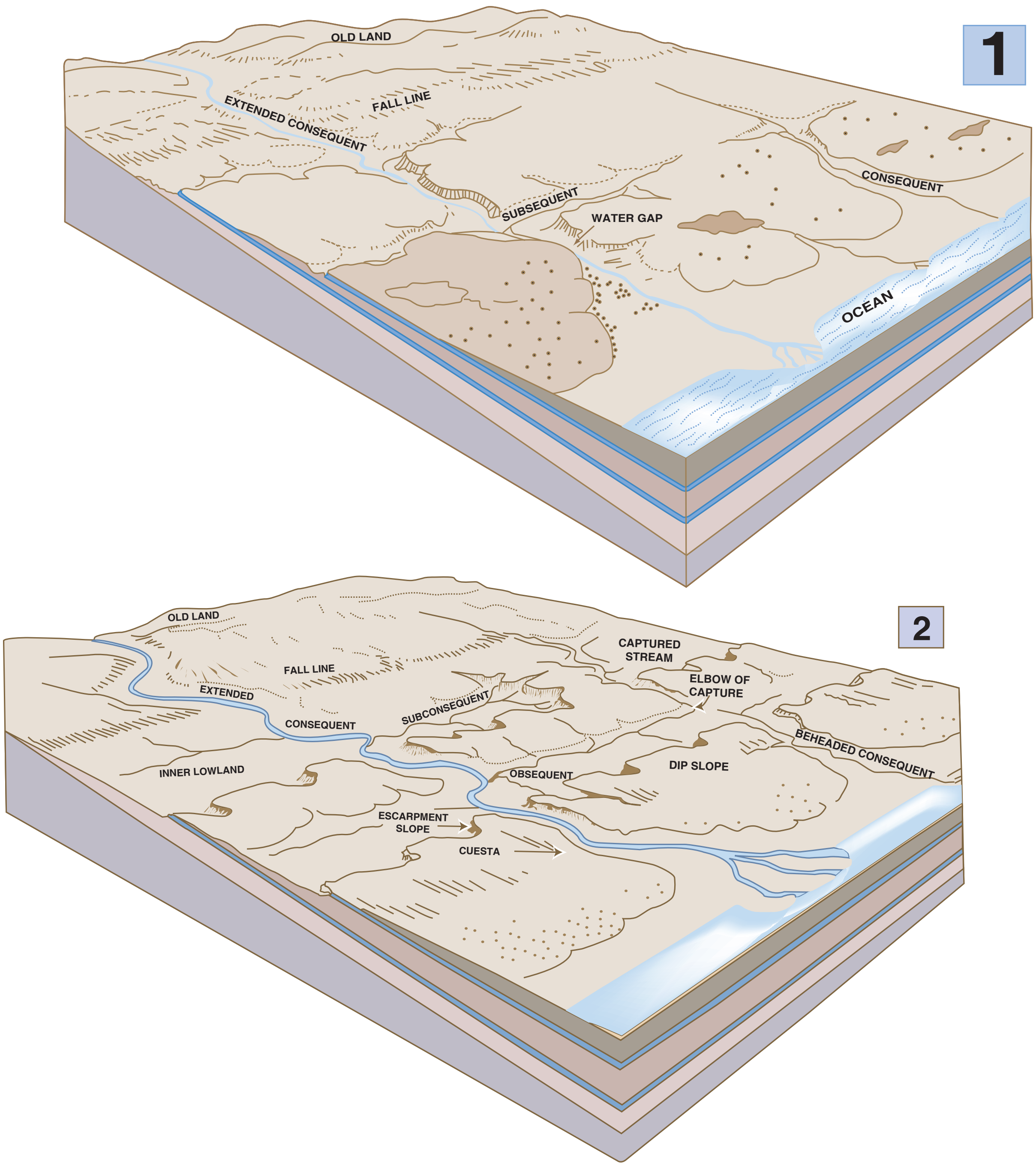


Figure by MIT OCW

Figure 11-5. A) Early stage in the development of drainage on an uplifted coastal plain. B) Later stage of development. (From von Engeln, 1942.)

4.4 In some places, certain of the consequent streams are larger than others, just because of the accidents of the original topography of the coastal-plain surface. These larger streams are likely to lower their profiles faster than adjacent consequent streams, especially if they are flowing on a weaker substrate. Then the subsequent tributaries to such consequent streams are able to extend themselves headward at lower elevations than the adjacent consequent streams. The lower subsequent stream then occupies a greater and greater drainage area at the expense of the drainage areas of adjacent subsequent streams, and eventually the divide might be eliminated altogether. The result is a diversion of the adjacent consequent stream into the drainage system of the larger consequent stream. This process is called ***stream piracy***, or ***stream capture*** (Figure 11-6). The captured consequent stream is said to be a ***beheaded stream***. Its valley, downstream of the point of capture, is then disproportionately large for the new, lesser discharge carried by the stream. The stream in such a valley is called an ***underfit stream***. One tip-off that capture has happened is an abrupt change of course, often at right angles (Figure 11-6B).

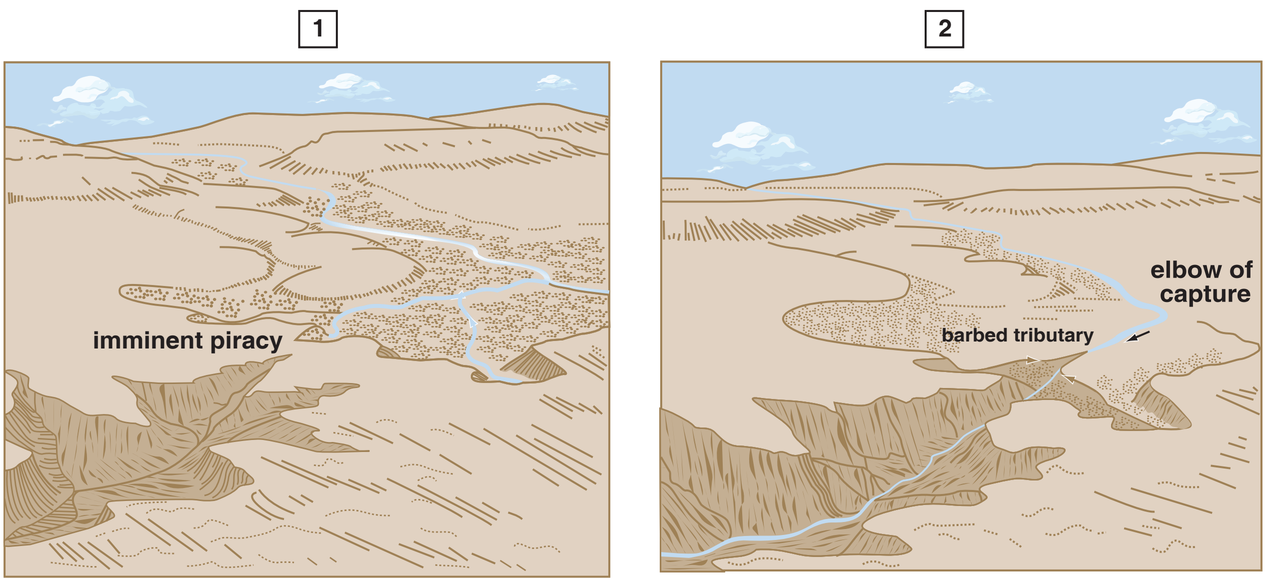


Figure by MIT OCW

Figure 11-6. Development of stream capture. A) Just before capture. B) Well after capture. (From von Engeln, 1942)

4.5 Consequent streams tend to encounter belts of rock that are strongly resistant to erosion. Ordinarily, however, they have sufficient erosive power to cut through such a belt of erosion-resistant rock as they lower their profiles, although the site may be a zone of rapids. As the adjacent belts of weaker rock are lowered by subsequent streams that are tributary to the consequent stream, a topographic ridge develops at the site of the belt of stronger rock, and a notch in the ridge, called a ***water gap***, develops (Figure 11-7). The Delaware water gap, on the Delaware River between northwestern New Jersey and northeastern Pennsylvania, and the Hudson Highlands water gap, along the lower course of the Hudson near West Point, where the Hudson cuts through the Precambrian highlands on its way south, are good examples of water gaps in the eastern US. Another good example is the Potomac River just downstream of its confluence with the Shenandoah River near Harper's Ferry. The rapids there figured prominently in George Washington's dream of making the Potomac River the principal gateway to the rapidly developing west after the War for American Independence.

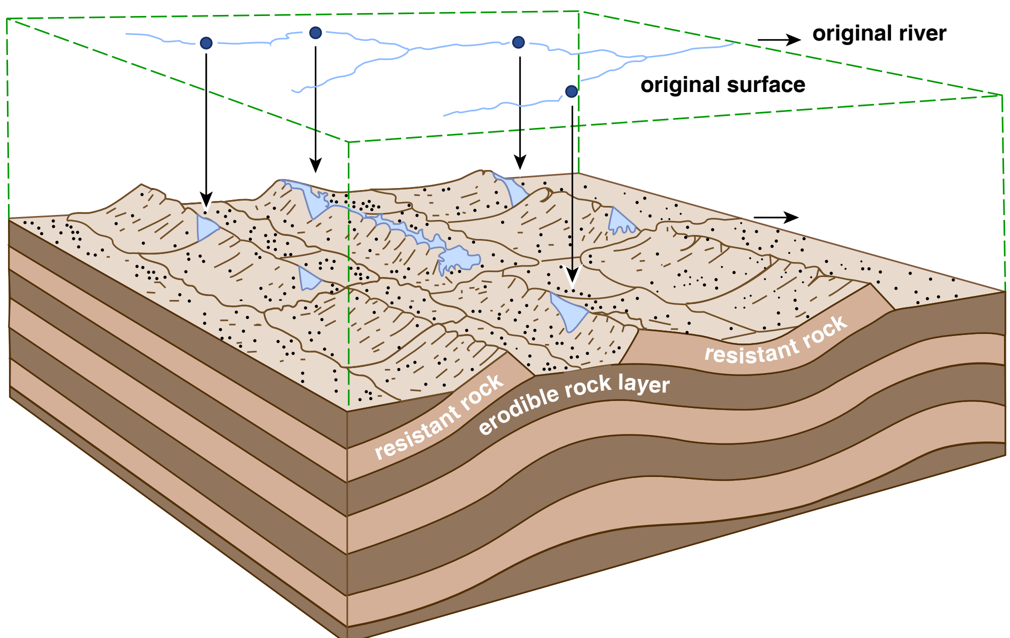


Figure 11-7. Development of water gaps and wind gaps. (From Bloom, 1998.)

4.6 Sometimes, when an aggressive subsequent stream captures an adjacent less aggressive consequent stream, a water gap through which the downstream reach of the captured stream flowed becomes abandoned. As the belts of weaker rock on either side of the ridge become lowered by further denudation, the former water gap appears as a ***wind gap***: a notch in the ridge high above the level of the adjacent valleys (Figure 11-7). You can see several wind gaps in the southeasternmost ridge of the valley and ridge province on Pennsylvania, as you drive southwest on Interstate Route 78 from the New Jersey border toward

Harrisburg. (Also, if you drive across the Susquehanna River on Pennsylvania Route 581 just south of Harrisburg, look north up the Susquehanna River to see a classic water gap.)

5. SOME COMMON GEOMORPHIC FEATURES PRODUCED BY FLUVIAL EROSION

5.1 Much of the landforms and landscapes we observe and admire are the result of fluvial erosion of regions underlain by sedimentary rock units, whether still flat-lying or now deformed. In this section we look at some of the common landscape features in such regions.

mesas and buttes. Many plateaus in arid or semiarid regions are surfaces capped by a particularly resistant horizontal sedimentary layer or sedimentary unit, underlain and overlain by softer, more easily erodible units. If the overlying weaker material is stripped away down to the level of the resistant unit, a plateau results. When fluvial erosion breaches the plateau and removes some of the weak rock underlying the resistant unit, broad areas of the plateau remain in partial or complete isolation from one another. Such a broad area is called a ***mesa*** (Figure 11-8). As the area of the mesa shrinks by wasting of the edges of the resistant layer and removal of more of the soft underlying material, the mesa becomes a ***butte*** (Figure 11-8).

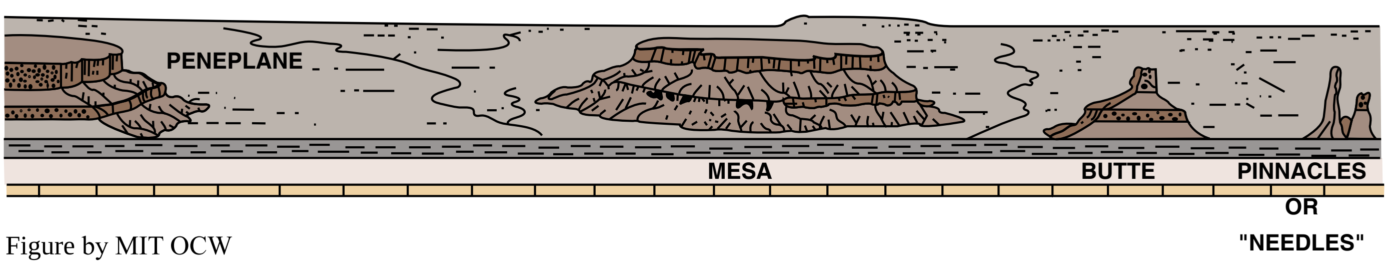


Figure by MIT OCW

Figure 11-8. Buttes and mesas. (From Lobeck, 1939)

cuestas and hogbacks. When a layer or unit of erosion-resistant rock, underlain and overlain by weaker rock, is gently dipping, fluvial erosion results in the resistant layer forming an asymmetrical ridge, called a ***cuesta***, with a gentle slope parallel to the layer and a steep slope perpendicular to the layer (Figure 11-9). The gentle slope is called a ***dip slope***. If the dip of the resistant unit is greater, the ridge is more nearly symmetrical; in that case, the ridge is called a ***hogback*** (Figure 11-9). When the dip of the strata is even steeper, the dip slopes sometimes form triangular facets, supported "from behind" by the mass of underlying strata (Figure 11-9). These are called ***flatirons***.

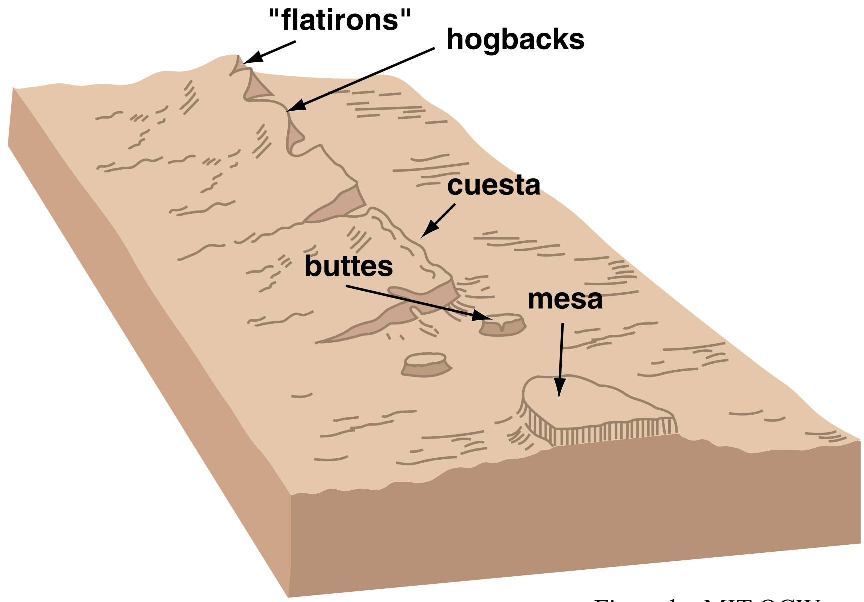


Figure 11-9. Cuestas, hogbacks, and flatirons. (From Bloom, 1998)

READINGS

Three of the most modern comprehensive treatments of geomorphology:

Allen, P.A., 1997, Earth Surface Processes. Blackwell Science, 404 p.

Bloom, A.L., 1998, Geomorphology; A Systematic Analysis of Late Cenozoic Landforms, Third Edition. Prentice Hall, 482 p. (especially Chapter 6)

Easterbrook, D.J., 1999, Surface Processes and Landforms, Second Edition. Prentice Hall, 546 p. (especially Chapter 15)

Two old books, with some outdated concepts but with superb illustrations (both photos and line drawings) of geomorphic features:

Lobeck, A.K., 1939, Geomorphology. McGraw-Hill, 731 p.

von Engeln, O.D., 1942, Geomorphology; Systematic and Regional. Macmillan, 655 p.

A classic textbook that covers a variety of geomorphic features and processes. Later editions are dumbed down.

Strahler, A.N., 1975, Physical Geography, Fourth Edition. Wiley, 643 p. + index and plates.

The classic book on fluvial geomorphology:

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial Processes in Geomorphology. Freeman, 522 p.