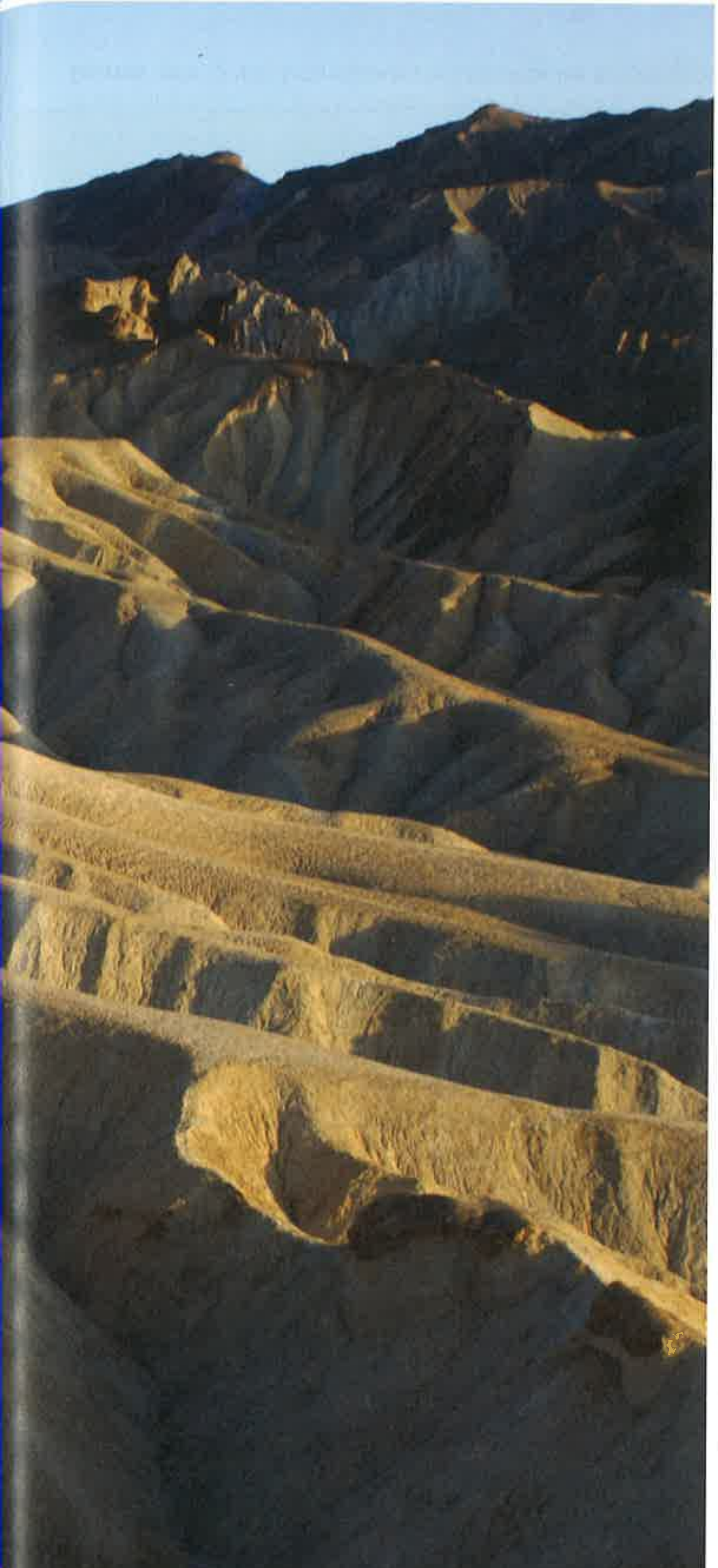


At Zabriskie Point, near Death Valley, it's too dry for vegetation to grow. So, during infrequent storms, the soft, tan rock erodes quickly.

Chapter Objectives

By the end of this chapter, you should know . . .

- why certain regions of the land have been classified as deserts, and what factors cause these regions to have arid climates.
- how weathering and erosional processes in deserts differ from those in temperate lands.
- the distinctive landforms and landscapes of deserts.
- how certain species of plants and animals survive desert climates, and how human activity may transform vegetated regions into deserts.

The bare hills are cut out with sharp gorges, and over their stone skeletons scanty earth clings. . . . A white light beat down, dispelling the last tract of shadow, and above hung the burnished shield of hard, pitiless sky.

—Clarence King (1842–1901; first director of the U.S. Geological Society, describing a desert)

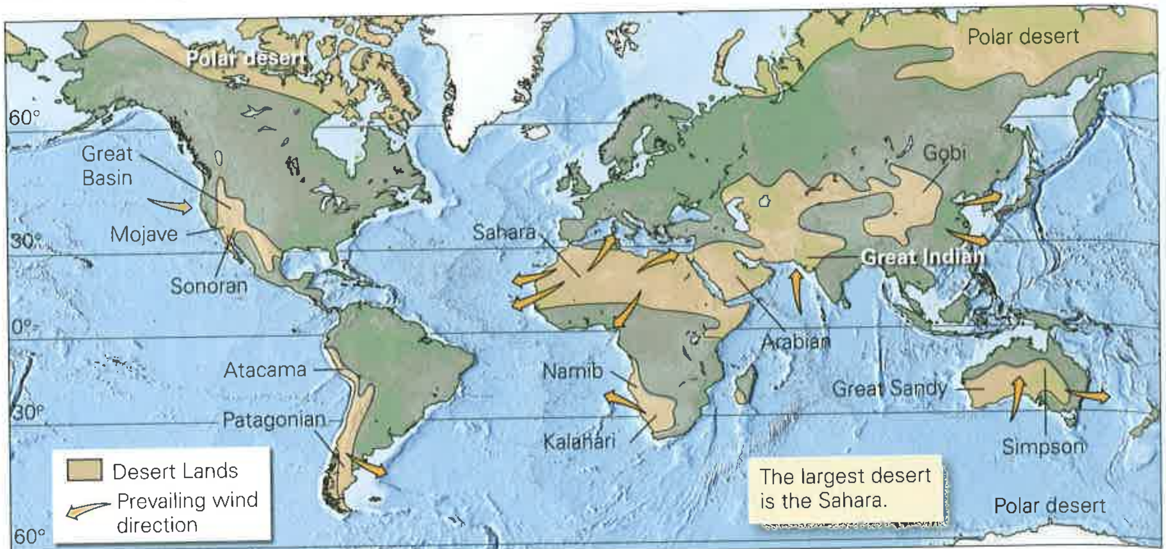
17.1 Introduction

For generations, nomadic traders have saddled camels to traverse the Sahara Desert in northern Africa (**Fig. 17.1a**). The Sahara, the world's largest desert, receives so little rainfall that it has hardly any surface water or vegetation. So camels must be able to walk for up to 3 weeks without drinking or eating. They can survive these journeys because they sweat relatively little; they have the ability to metabolize their own body fat to produce new water; and they can withstand severe dehydration.

The survival challenges faced by a camel emphasize that deserts are lands of extremes—extreme dryness, heat, cold, and, in some places, beauty. Desert vistas include everything from sand seas to sagebrush plains, cactus-covered hills to endless stony pavements. Although less populated than other regions on Earth, deserts cover about 25% of the land surface, and thus constitute an important component of the Earth System (**Fig. 17.1b**). In this chapter, we take a look at the desert landscape. We learn why deserts occur where they do, and how erosion and deposition shape their surface. We conclude by exploring life in the desert and by examining the problem of desertification, the gradual transformation of temperate lands into desert.

FIGURE 17.1 Deserts and their hardy inhabitants.

(a) Camels can survive the harsh desert conditions of the Arabian Desert.



(b) The global distribution of deserts. Arid regions cover 25% of the land surface.

17.2 The Nature and Locations of Deserts

What Is a Desert?

Formally defined, a **desert** is a region that is so arid (dry) that it supports vegetation on no more than 15% of its surface. In general, desert conditions exist where less than 25 cm of rain falls per year, on average. Because of the lack of water, deserts contain no permanent streams, except for those that bring water in from temperate regions elsewhere.

Note that the definition of a desert depends on a region's aridity, not on its temperature. Geologists, therefore, distinguish between cold deserts, where temperatures generally stay below about 20°C for the year, and hot deserts, where summer daytime temperatures exceed 35°C. Cold deserts exist at high latitudes where the Sun's rays strike the Earth obliquely and thus don't provide much energy, at high elevations where the air is too thin to hold much heat, or in lands adjacent to cold oceans, where the cold water absorbs heat from the air above. Hot deserts develop at low latitudes where the Sun's rays strike the desert at a high angle, at low elevations where dense air can hold a lot of heat, and in regions distant from the cooling effect of cold ocean currents. The hottest recorded temperatures on Earth occur in low-latitude, low-elevation deserts—58°C (136°F) in Libya and 57°C (133°F) in Death Valley, California.

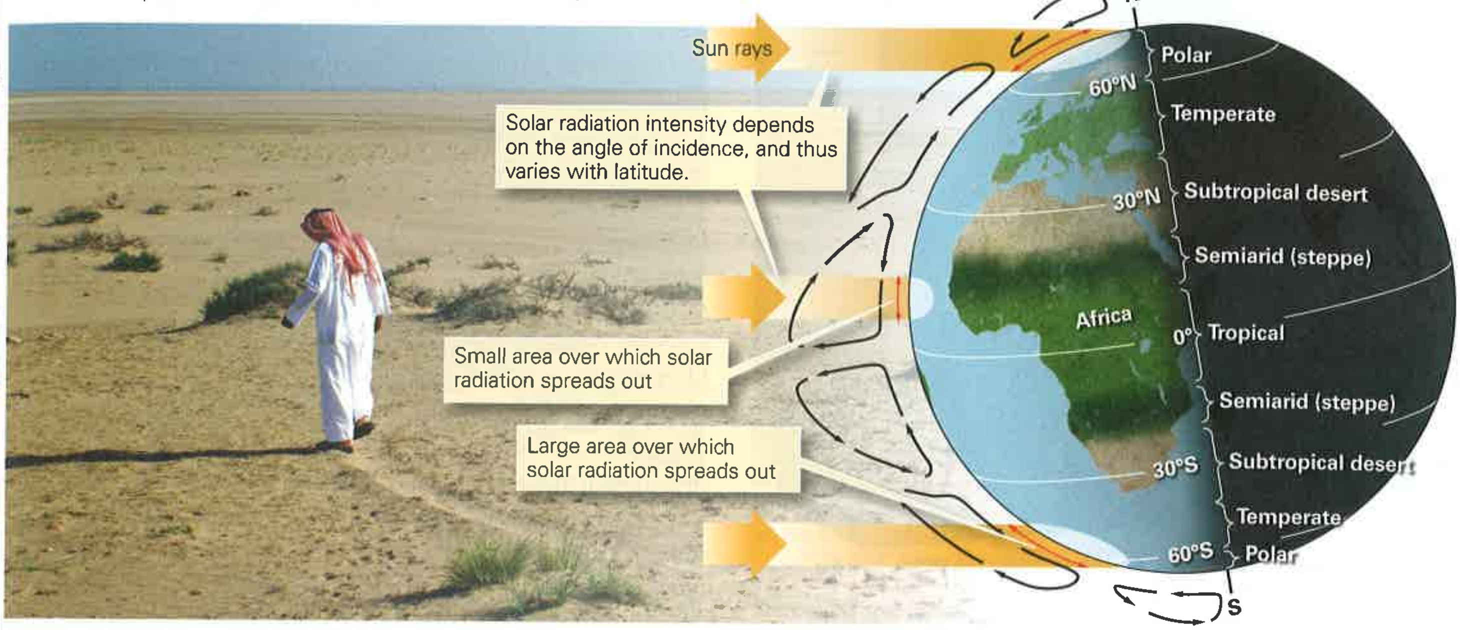
Did you ever wonder . . .
how hot can it become in a desert?

Types of Deserts

Each desert on Earth has unique characteristics of landscape and vegetation that distinguish it from others. Geologists group deserts into five different classes, based on the environment in which the desert forms (**Fig. 17.2**).

- *Subtropical deserts*: Subtropical deserts (such as the Sahara, Arabian, Kalahari, and Australian) form because of the regional pattern of air circulation in the atmosphere. At the equator, the air becomes warm and humid, for sunlight is intense and water rapidly evaporates from the ocean. The hot, moisture-laden air rises to great heights above the equator. As this air rises, it expands and cools, and can no longer hold so much moisture. Water condenses and falls in downpours that feed the lushness of the equatorial rain forest. The now-dry air high in the troposphere spreads laterally north or south. When this air reaches latitudes of 20° to 30°, a region called the subtropics, it has become cold and dense enough to sink. Because the air is dry, no clouds form, and intense solar radiation strikes the Earth's surface. The sinking, dry air becomes denser and heats up, soaking up any moisture present. In the regions swept by this hot air on its journey back to the equator, evaporation rates greatly exceed rainfall rates, so the land becomes parched.
- *Deserts formed in rain shadows*: As air flows over the sea toward a coastal mountain range, the air must rise (**Fig. 17.3**). As the air rises, it expands and cools. The water it contains condenses and falls as rain on the seaward flank of the mountains, nourishing a coastal rain forest. When the air finally reaches the inland side of the mountains, it has lost all its moisture and can no longer provide rain. As a consequence, a **rain shadow** forms, and the land beneath the rain shadow becomes a desert. A rain-shadow desert can be found east of the Cascade Mountains in the state of Washington.

FIGURE 17.2 Subtropical deserts form because the air that convectively flows downward in the subtropics warms and absorbs water as it sinks.



- *Coastal deserts formed along cold ocean currents*: Cold ocean water cools the overlying air by absorbing heat, thereby decreasing the capacity of the air to hold moisture. For example, the cold Humboldt Current, which carries water northward from Antarctica to the western coast of South America, cools the air that blows east, over the coast. The air is so dry when it reaches the coast that rain rarely falls on the coastal areas of Chile and Peru. As a result, this region hosts a desert landscape, including one of the driest deserts in the world, the Atacama (**Fig. 17.4a, b**). Portions of this narrow desert received no rain at all between 1570 and 1971.
- *Deserts formed in the interiors of continents*: As air masses move across a continent, they lose moisture by dropping rain, even in the absence of a coastal mountain range. Thus, when an air mass reaches the interior of a broad continent, it has become so dry that the land beneath becomes arid. The largest present-day example of such a continental-interior desert, the Gobi, lies in central Asia.
- *Deserts of the polar regions*: So little precipitation falls in Earth's polar regions (north of the Arctic Circle and south of the Antarctic Circle) that these areas are, in fact, arid. Polar regions are dry, in part, for the same reason that the subtropics are dry (the global pattern of air circulation means that the air flowing over these regions is dry), and in part, for the same reason that coastal areas along cold currents are dry (cold air holds little moisture).

Different regions of the land surface have become deserts at different times in the Earth's history, because plate movements change the latitude of landmasses, the position of landmasses relative to the coast, and the proximity of landmasses to a mountain range. Because of plate tectonics, some regions that were deserts in the past are temperate or tropical regions now, and vice versa.

Take-Home Message

Deserts are so arid that they host only very sparse vegetation. They occur in several settings: subtropical dry climates, rain shadows, coasts bordered by cold currents, continental interiors, and polar regions.

FIGURE 17.3 The formation of a rain-shadow desert. Moist air rises and drops rain on the coastal side of the range. By the time the air has crossed the mountains, it is dry.

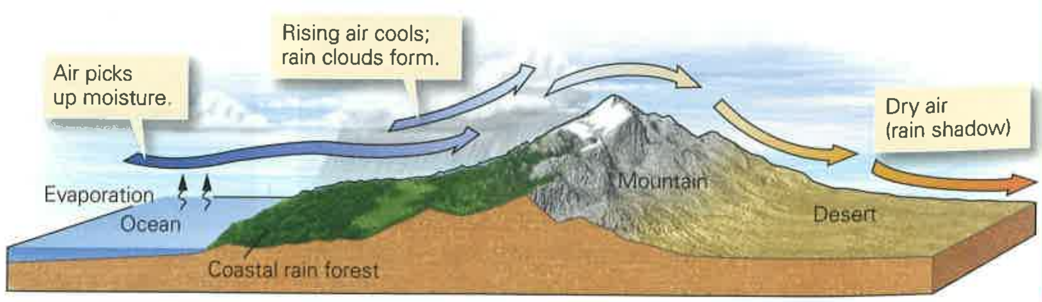
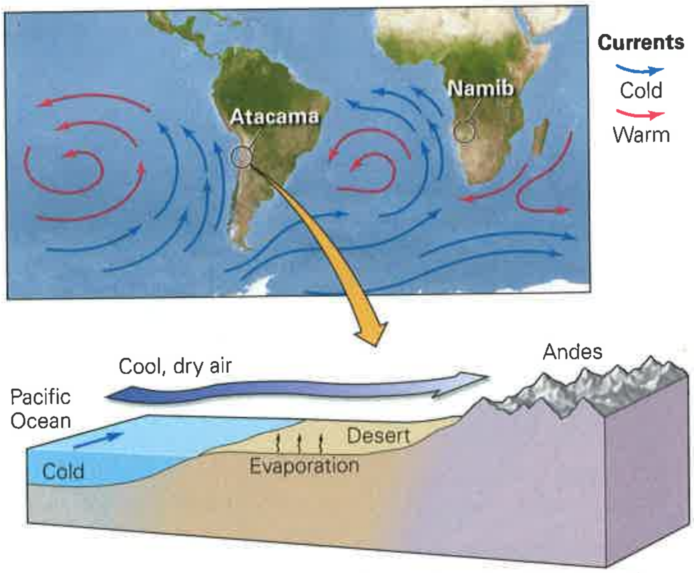


FIGURE 17.4 The formation of a coastal desert.



(a) Cold ocean currents cool and dry the air along the coast. This air absorbs moisture from adjacent coastal land.

(b) The Atacama Desert is the driest place on Earth.

17.3 Weathering and Erosional Processes in Deserts

Without the protection of foliage to catch rainfall and slow the wind, and without roots to hold regolith in place, rain and wind can attack and erode the land surface of deserts and soil tends to be sparse. The result, as we have noted, is that hillslopes are typically bare, and plains can be covered with stony debris or drifting sand.

Arid Weathering and Desert Soil Formation

In the desert, as in temperate climates, physical weathering happens primarily when joints (natural fractures) split rock into pieces. Joint-bounded blocks eventually break free of bedrock and tumble down slopes, fragmenting into smaller pieces as they fall. In temperate climates, thick soil develops and covers bedrock. In deserts, however, bedrock commonly remains exposed, forming rugged, rocky escarpments.

Chemical weathering happens more slowly in deserts than in temperate or tropical climates, because less water is available to react with rock. Still, rain or dew provides enough moisture for some weathering to occur. This water seeps into rock and leaches (dissolves and carries away) calcite, quartz, and various salts. Leaching effectively rots the rock by transforming it into a poorly cemented aggregate. Over time, the rock will crumble and form a pile of unconsolidated sediment, susceptible to transport by water or wind.

Although enough rain falls in deserts to leach chemicals out of sediment and rock, there is not enough rain to carry the chemicals away entirely. So they precipitate to form calcite and other minerals in regolith beneath the surface. The new minerals may bind clasts together to form a rock-like material called *calcrete*.

Shiny **desert varnish**, a dark, rusty brown coating of iron oxide, manganese oxide, and clay, may cover the surface of rocks in deserts (**Fig. 17.5a**). Desert varnish was once thought to form when water from rain or dew seeped into a rock, dissolved iron and magnesium ions, and carried the ions back to the surface of the rock by capillary action. More recent studies, however, suggest that desert varnish is not necessarily derived from the rock it coats. Instead, the iron and manganese in the varnish may come from dust that settles on the surface of the rock, for in the presence of moisture, microorganisms (bacteria and archaea) can extract iron and manganese from the dust and transform it into oxide minerals. Such varnish won't form in humid climates, because rain washes away the dust.

Desert varnish takes a long time to form. In fact, the thickness of a desert varnish layer provides an approximate estimate of how long a rock has been exposed at the ground surface. In past centuries, Native Americans used desert-varnished rock as a medium for art: by chipping away the varnish to reveal the underlying lighter-colored rock, they were able to create figures or symbols on a dark background. The resulting drawings are called **petroglyphs**.

Because of the lack of plant cover in deserts, variations in bedrock and soil color visually stand out. Slight variations in the concentration of iron, or in the degree of iron oxidation, in adjacent beds result in spectacular color bands in rock layers and the thin soils derived from them. The Painted Desert of northern Arizona earned its name from the brilliant and varied hues of oxidized iron in the region's shale bedrock (**Fig. 17.5b**).

Water Erosion

Although rain rarely falls in deserts, when it does come, it can radically alter a landscape in a matter of minutes. Since deserts

FIGURE 17.5 Soil formation and chemical weathering in deserts.

(a) Native Americans chiseled this petroglyph of a snake into desert varnish on a Utah boulder.

(b) The red hues of the Painted Desert in Arizona are due to the oxidation of iron in the rock.

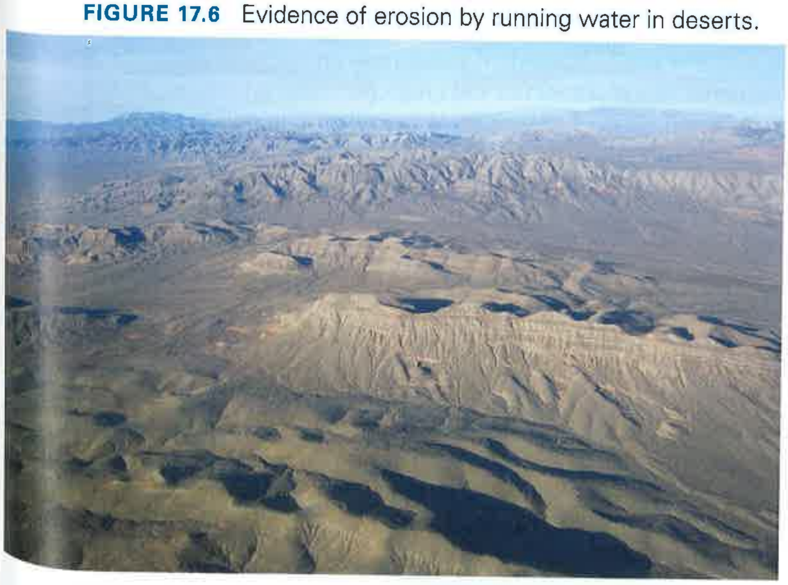
lack plant cover, rainfall, sheetwash, and stream flow are all extremely effective agents of erosion. It may seem surprising, but water generally causes more erosion than does the wind in most deserts (**Fig. 17.6a**).

Water erosion begins with the impacts of raindrops, which eject sediment from the ground into the air. On a hill, the ejected sediment lands downslope. The ground quickly becomes saturated with water during a heavy rain, so water starts flowing across the surface, carrying the loose sediment with it. Within minutes after a heavy downpour begins, dry stream channels fill with a turbulent mixture of water and sediment, which rushes downstream as a flash flood. When the rain stops, the water sinks into the stream bed's gravel and disappears—such streams are called intermittent, or ephemeral streams (see Chapter 14). Because of the relatively high viscosity of the water (owing to its load of suspended sediment) and the velocity and turbulence of the flow, flash floods in deserts cause intense erosion. Dry stream channels in desert regions of southwestern North America are called **dry washes**, or **arroyos**, and in the Middle East and North Africa they are called wadis (**Fig. 17.6b**).

Wind Erosion

In temperate and humid regions, plant cover protects the ground surface from the wind, but in deserts, the wind has direct access to the ground. Wind, just like flowing water, can carry sediment both as suspended load and as surface load.

FIGURE 17.6 Evidence of erosion by running water in deserts.

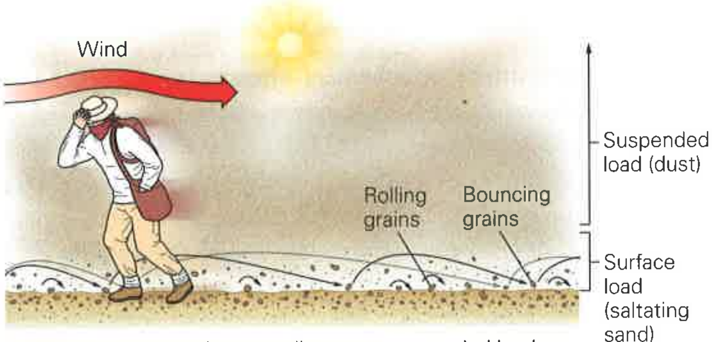


(a) These hills in the desert near Las Vegas, Nevada, are bone dry, but their shape indicates erosion by water. Note the numerous stream channels.

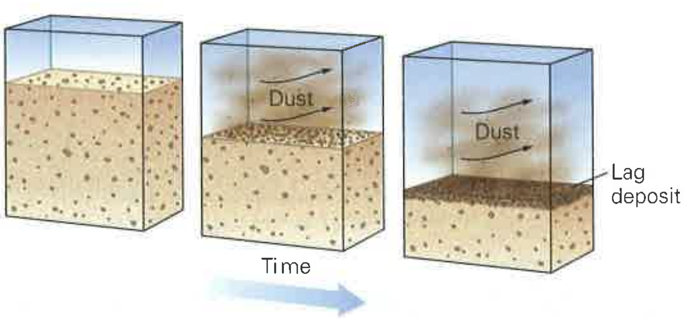
(b) Gravel and sand are left behind on the floor of a dry wash after a flash flood in Death Valley. Erosion by the water is cutting a channel.

FIGURE 17.7 Sediment transport by wind in deserts.

(a) A huge dust storm approaching Phoenix, Arizona.



(b) Wind transports desert sediment as suspended load and surface load.



(c) A lag deposit develops when wind blows away finer sediment, leaving behind a layer of coarser grains.

Suspended load (fine-grained sediment such as dust and silt held in suspension) stays in the air for a long time and moves with it. The suspended sediment can be carried so high into the atmosphere (up to several kilometers above the Earth's surface) and so far downwind (tens to thousands of kilometers) that it may move completely out of its source region. Particularly strong winds can generate a dramatic **dust storm**, or haboob, that can be 100 km long and 1.5 km high (**Fig. 17.7a**). A dust storm, as it approaches, looks like a roiling, opaque wave. A particularly large one engulfed Phoenix, Arizona, in 2011, and shut down the airport. Dust storms are fairly common in the Sahara and Arabian Deserts, where they are known as haboobs.

Surface loads, or bed loads, start moving only in moderate to strong winds, for such winds can roll and bounce sand grains along the ground, a process called **saltation**. Saltation begins when turbulence caused by wind shearing along the ground surface lifts sand grains. The grains move downwind, following an asymmetric, arch-like trajectory. Eventually, they return to the ground, where they strike other sand grains, causing the new grains to bounce up and drift or roll downwind. The collisions between sand grains make the grains rounded and frosted. Saltating grains generally rise no more than 0.5 m, but where sand bounces on bedrock the grains may rise 2 m.

The size of clasts that wind can carry depends on the wind velocity. Wind, therefore, does an effective job of sorting sediment, sending dust-sized particles skyward and sand-sized particles bouncing along the ground, while pebbles and larger grains remain behind. In some cases, wind carries away so much fine sediment that pebbles and cobbles become concentrated at the ground surface (**Fig. 17.7b, c**). An accumulation of coarser sediment left behind when fine-grained sediment blows away is called a **lag deposit**.

Just as sandblasting cleans the grime off the surface of a building, windblown sand and dust grind away at surfaces in the desert. Over long periods of time, such wind abrasion creates smooth faces, or facets, on pebbles, cobbles, and boulders. If a rock rolls or tips relative to the prevailing wind direction after it has been faceted on one side, or if the wind shifts direction, a new facet with a different orientation forms, and the two facets join at a sharp edge. Rocks whose surface has been faceted by the wind are faceted rocks, or **ventifacts** (**Fig. 17.8**). Wind abrasion also gradually polishes and bevels down irregularities

FIGURE 17.8 The progressive development of a ventifact.

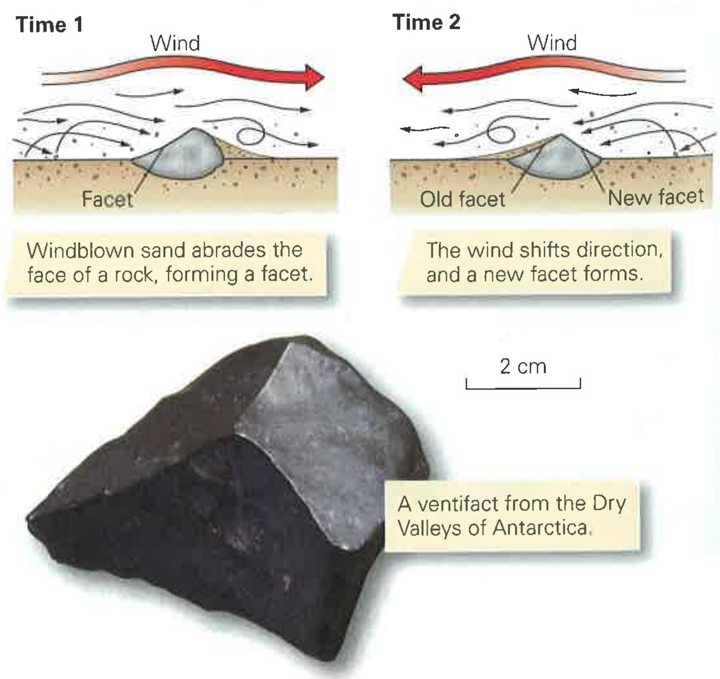


FIGURE 17.9 Wind erosion in Death Valley has left bushes perched on mounds; roots keep soil from blowing away.

on a desert pavement and polishes the surfaces of desert-varnished outcrops, giving them a reflective sheen.

Over time, in regions where the substrate consists of soft sediment, wind picks up and removes so much sediment that the land surface becomes lower. The process of lowering the land surface by wind erosion is called **deflation**. Shrubs can stabilize a small patch of sediment with their roots, so after deflation a forlorn shrub with its residual pedestal of soil stands isolated above a lowered ground surface (**Fig. 17.9**). In some places, the shape of the land surface twists the wind into a turbulent vortex that causes enough deflation to scour a deep, bowl-like depression called a blowout.

Take-Home Message

Physical weathering dominates in deserts. Soils are thin, and desert varnish may coat rock surfaces. Water causes most erosion and sediment transport but rarely flows, so stream channels are dry washes. Wind transports sediment and carves ventifacts.

17.4 Deposition in Deserts

We've seen that erosion relentlessly eats away at bedrock and sediment in deserts. Where does the debris go? Below, we examine the various desert settings in which sediment accumulates.

Talus Aprons

Over time, joint-bounded blocks of rock break off ledges and cliffs on the sides of hills. Under the influence of gravity, the resulting debris tumbles downslope and accumulates as **talus**, a pile of debris at the base of a hill. Talus can survive for a long time in desert climates, so we typically see aprons of talus fringing the bases of cliffs in deserts (**Fig. 17.10a**).

Alluvial Fans

Flash floods can carry sediment downstream in a steep-walled canyon. In some cases, the water contains so much sediment that it is best called a debris flow (see Chapter 13). When the turbulent water flows out into a plain at the mouth of a canyon, it spreads out over a broader surface and slows. As a consequence, sediment in the water settles out. The channel that emerges from the mountains tends to subdivide into a number of subchannels or distributaries that diverge outward. The network of distributaries spreads the sediment, or alluvium, out into a broad **alluvial fan**, a wedge- or apron-shaped pile of sediment (**Fig. 17.10b**). Alluvial fans emerging from adjacent valleys may merge and overlap along the front of a

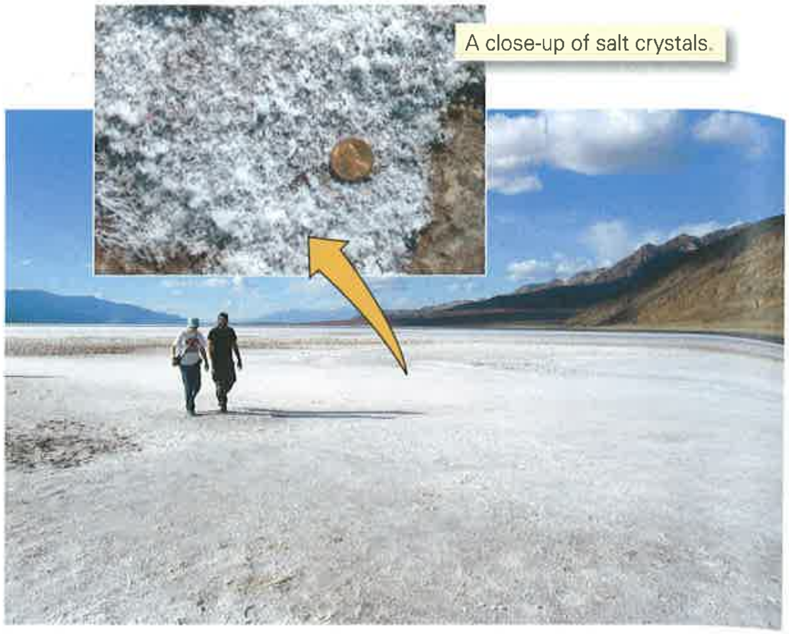
FIGURE 17.10 Production and transportation of debris and sediment in deserts.

(a) This talus apron along the base of a desert cliff formed from rocks that broke off and tumbled down the cliff.

(b) Sediment in this alluvial fan in Death Valley was carried by flash floods. The fan forms at the mountain front where water slows.

FIGURE 17.11 Playas form where a shallow, salty lake dries up.

(a) This playa in southern California formed at the base of a bajada.



(b) White salt crystals encrust the floor of a playa in Death Valley.

mountain range, producing an elongate wedge of sediment called a bajada. Over long periods, the sediment of bajadas can fill in adjacent valleys to depths of several kilometers.

Playas and Salt Lakes

Water from a flash flood occasionally reaches the center of an alluvium-filled basin. But if the supply of water is relatively small, the water quickly sinks into the permeable alluvium without accumulating as a standing body. During a particularly large storm or an unusually wet spring, however, a temporary lake may develop over the low part of a basin. During drier times, such desert lakes evaporate entirely, leaving behind a dry, flat, exposed lake bed known as a **playa** (**Fig. 17.11a, b**). Over time, a smooth crust of clay and various salts (halite, gypsum, borax, and other minerals) accumulates on the surface of playas.

Where sufficient water flows into a desert basin, it creates a permanent lake. If the basin is an interior basin, with no outlet to allow water to flow out, the lake becomes very salty, because although its water escapes by evaporation in the desert sun, its salt cannot. The Great Salt Lake, in Utah, exemplifies this process. Even though the streams feeding the lake are fresh enough to drink, their water contains trace amounts of dissolved salt ions. Because the lake has no outlet, these ions have become concentrated in the lake over time, making it even saltier than the ocean.

Deposition from the Wind

As mentioned earlier, wind carries two kinds of sediment loads—a suspended load of dust-sized particles and a surface load of sand. Much of the dust is carried out of the desert and accumulates elsewhere. Sand, however, cannot travel far, and accumulates within the desert in piles called **dunes**, ranging in size from less than a meter to over 300 m high. In favorable locations, dunes accumulate to form vast "sand seas." We'll look at dunes in more detail later in this chapter.

Take-Home Message

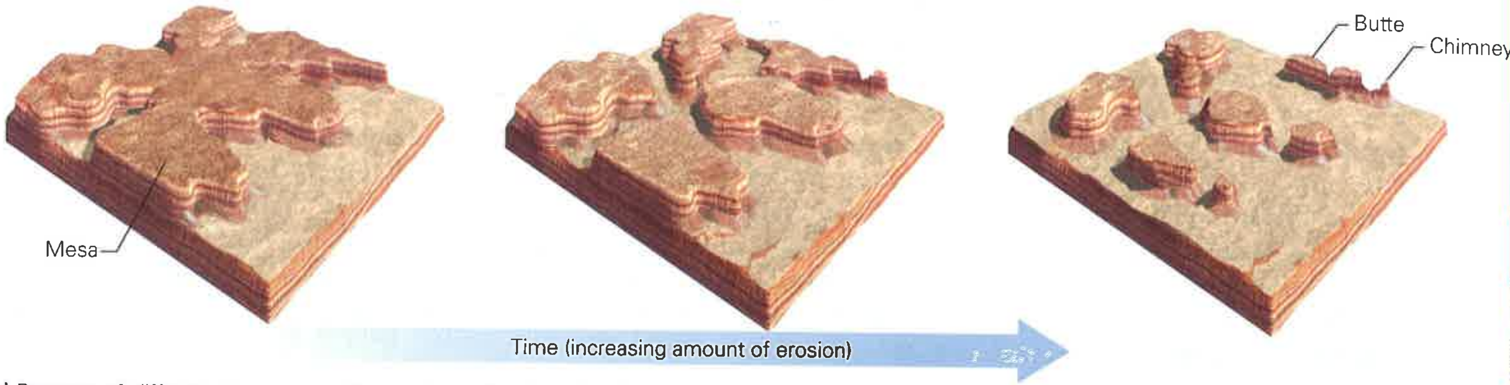
Sediment carried by water and wind in deserts accumulates in a variety of landforms. Alluvial fans form at the outlets of canyons, playas form where water temporarily collects in basins, and dunes form where large amounts of sand are available.

17.5 Desert Landscapes and Life

The popular media commonly portray deserts as endless vistas of sand, punctuated by the occasional palm-studded oasis. In reality, not all desert landscapes are buried by sand. Some deserts are vast, rocky plains; others sport a stubble of cacti and other hardy desert plants; and still others display intricate rock formations that look like medieval castles (**See for Yourself Q**). Explorers of the Sahara, for example, traditionally distinguished among hamada (barren, rocky highlands), reg (vast, stony plains), and erg (sand seas in which large dunes form).

Did you ever wonder . . . are all deserts completely covered by sand?

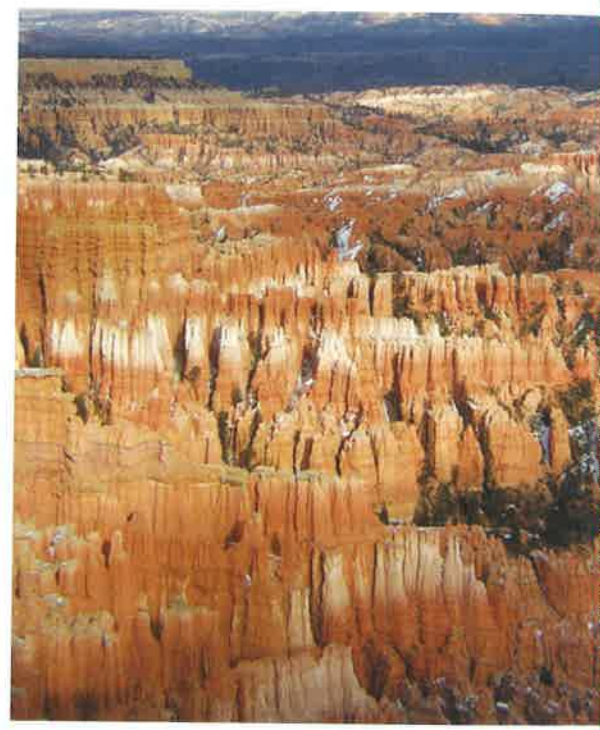
FIGURE 17.12 Mesas and buttes form in deserts as cliffs retreat over time.



(a) Because of cliff retreat, a once-continuous layer of rock evolves into a series of isolated remnants. If the bedding is horizontal, the resulting landforms have flat tops.

(b) Buttes and mesas tower above the floor of Monument Valley, Arizona.

In this section, we'll see how the erosional and depositional processes described above lead to the formation of such contrasting landscapes.



(c) Erosion produced many chimneys in Bryce Canyon, Utah. These features are locally known as "hoodoos."

Rocky Cliffs and Mesas

In hilly desert regions, the lack of soil exposes rocky ridges and cliffs. As noted earlier, cliffs erode when rocks split away along joints. When this happens, the cliff face steps back into the land but retains roughly the same form. The process, commonly referred to as **cliff retreat**, or scarp retreat, occurs in fits and starts. A cliff may remain unchanged for decades or centuries, and then suddenly a block of rock falls off and crumbles into rubble at the foot of the cliff. Cliffs exposing alternating layers of strata with contrasting strength develop a step-like shape; strong layers (sandstone or limestone) become vertical cliffs, and weak layers (shale) become rubble-covered slopes.

With continued erosion and cliff retreat, a plateau of rock slowly evolves into a cluster of isolated hills, ridges, or columns. Flat-lying strata or flat-lying layers of volcanic rocks erode to make flat-topped hills, which go by different names depending on their size. Large examples (with a top surface area of several square km) are **mesas**, from the Spanish word for table. Medium-sized examples are **buttes** (**Fig. 17.12a, b**), and small examples, whose height greatly exceeds their top surface area, are **chimneys** (**Fig. 17.12c**).

Natural arches form when erosion along joints leaves narrow walls of rock. When the lower part of the wall erodes while the upper part remains, an arch results. (See **Geology at a Glance**, pp. 510–511.)

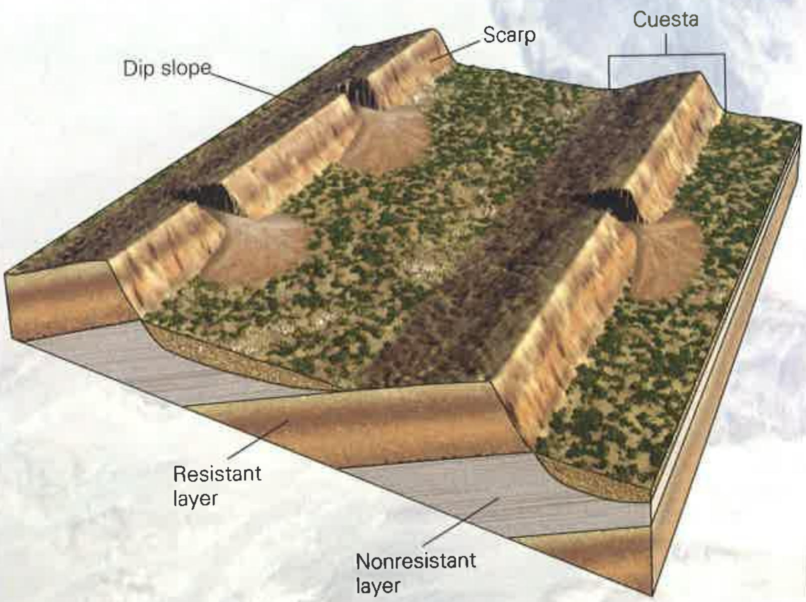
In places where bedding dips at an angle, an asymmetric ridge called a *cuesta* develops. A joint-controlled cliff forms the steep front side of a cuesta, and the tilted top surface of a resistant bed forms the gradual slope on the backside (**Fig. 17.13a**). If the bedding dip is steep to near vertical, a narrow symmetrical ridge, called a *hogback*, forms.

After a long period of erosion, all that may remain of a once broad region of uplifted land is a relatively small island of rock, surrounded by alluvium-filled basins. Geologists refer to such islands of rock by the German word **inselberg** (island mountain; **Fig. 17.13b**). Depending on the rock type or the orientation of stratification in the rock, and on rates of erosion, inselbergs may be sharp-crested, plateau-like, or loaf-shaped (steep sides and a rounded crest). Inselbergs with a loaf geometry, as exemplified by Uluru (Ayers Rock) in central Australia (**Fig. 17.13c**), are also known as bornhardts.

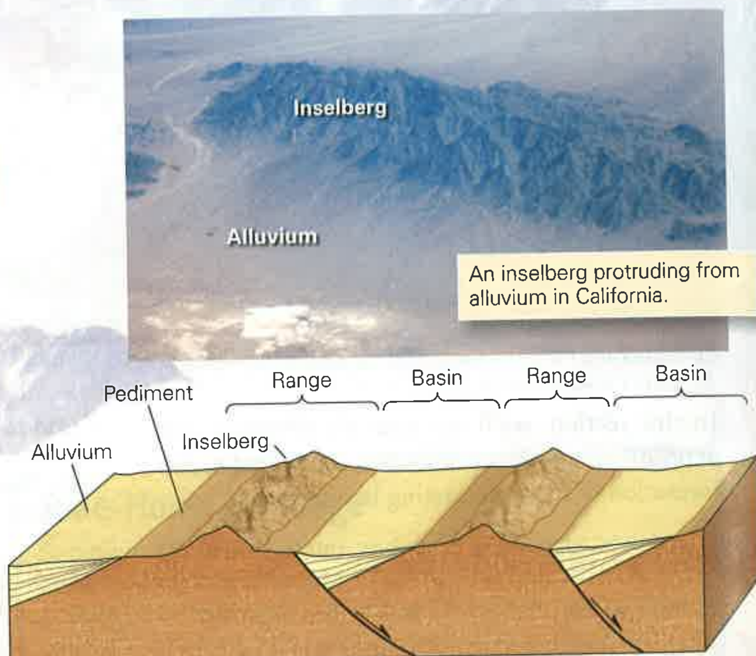
Desert Pavement

In many locations, the desert surface resembles a tile mosaic in that it consists of separate stones that fit together tightly, forming a fairly smooth surface layer above a soil composed of silt and clay. Such natural mosaics constitute **desert pavement** (**Fig. 17.14a, b**). Typically, desert varnish coats the top surfaces of the stones forming desert pavement. Recently, researchers have suggested that pavements form when windblown dust slowly sifts down onto the stones and then washes down between the stones. In this model, the pavement is "born at the surface," meaning that the stones forming the pavement were never buried, but have been progressively lifted up as soil collects and builds up beneath (**Fig. 17.14c**). Over time, the rocks at the surface crack, perhaps due to differential heating by the desert sun. Sheetwash, during downpours, may wash away fine sediment between fragments, and when soils dry and shrink between storms, the clasts settle together, locking into a stable, jigsaw-like arrangement.

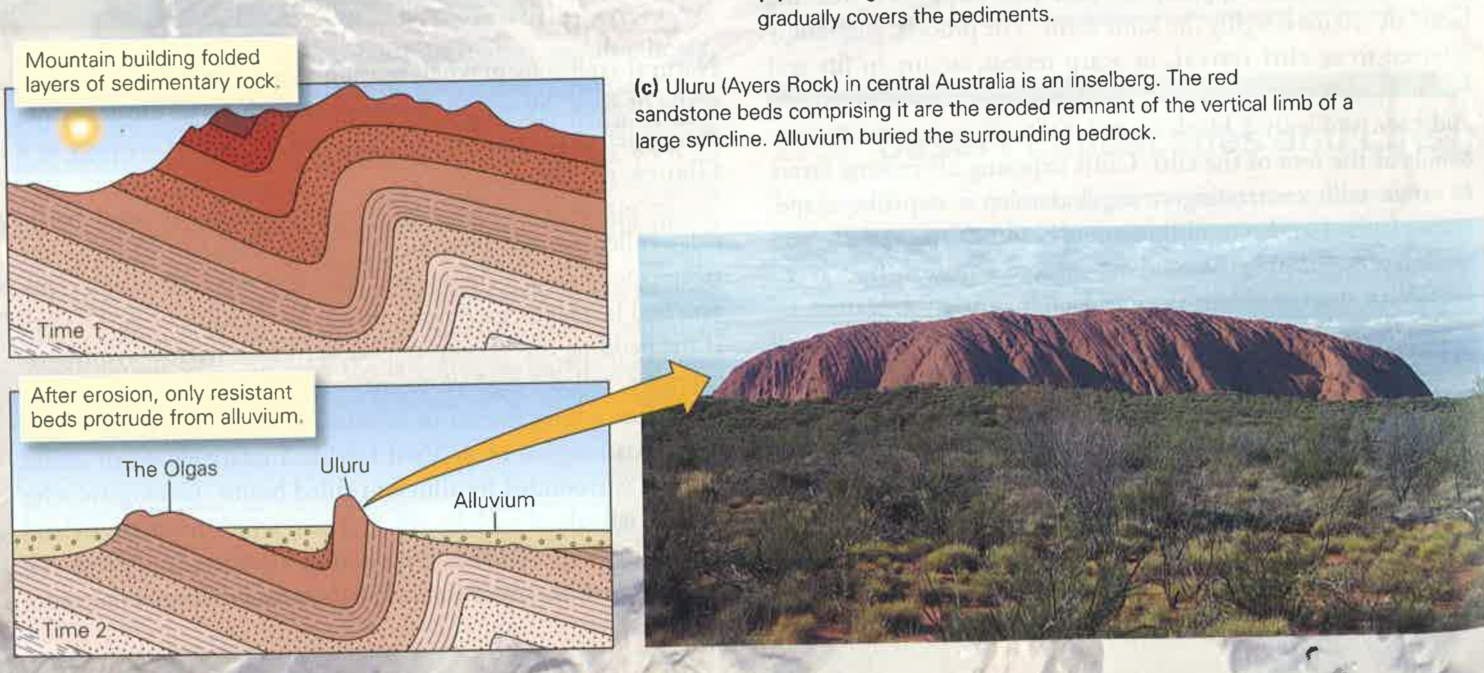
FIGURE 17.13 The formation of cuestas and inselbergs, due to erosion and deposition in deserts.



(a) Asymmetric ridges called cuestas develop where strata in a region are not horizontal.



(b) Inselbergs are small islands of rock surrounded by pediments. Alluvium gradually covers the pediments.



(c) Uluru (Ayers Rock) in central Australia is an inselberg. The red sandstone beds comprising it are the eroded remnant of the vertical limb of a large syncline. Alluvium buried the surrounding bedrock.

Stony Plains and Pediments

The coarse sediment eroded from desert mountains and ridges washes into adjacent lowlands and builds out to form gently sloping alluvial fans. The surfaces of these gravelly piles are strewn with pebbles, cobbles, and boulders, and are dissected by dry washes (wadis or arroyos). Portions of these stony plains may evolve into desert pavements.

When travelers began trudging through the desert of the southwestern United States during the 19th century, they found that in many locations the wheels of their wagons were rolling over flat or gently sloping bedrock surfaces. These bedrock surfaces extended outward like ramps from the steep cliffs of a mountain range on one side, to the alluvium-filled valleys on the other (see Fig. 17.13b). Geologists now refer to such surfaces as **pediments**. Pediments develop when sheetwash during floods carries sediment away from the mountain front, during mountain-front retreat. The moving sediment grinds away the bedrock that it tumbles over.

Seas of Sand: The Nature of Dunes

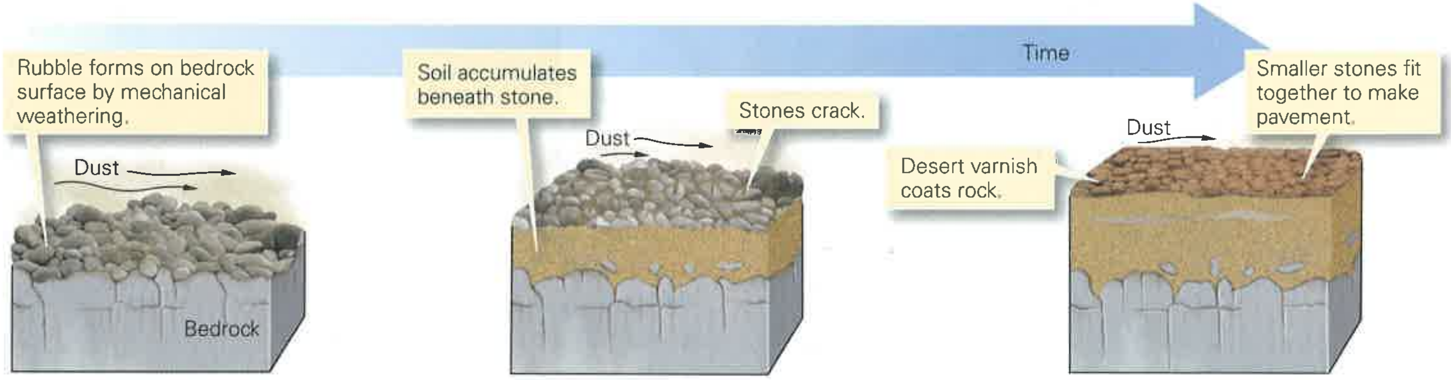
A **sand dune** is a pile of sand deposited by a moving current. Dunes in deserts may start to form where sand becomes trapped on the windward side of an obstacle, such as a rock or a shrub. Gradually, the sand builds downwind into the lee of the obstacle. Dunes display a variety of shapes and sizes, depending on the character of the wind and the sand supply (**Fig. 17.15a**). Where the sand is relatively scarce and the wind blows steadily in one direction, beautiful crescents called *barchan dunes* develop, with the tips of the crescents pointing downwind. If the wind shifts direction frequently, a group of crescents pointing in different directions overlap one another, creating a constantly changing *star dune*. Where enough sand accumulates to bury the ground surface completely, and only moderate winds blow, sand piles into simple, wave-like shapes called *transverse dunes*. The crests of transverse dunes lie perpendicular to the wind direction. Strong winds may break through transverse dunes and change them into *parabolic dunes* whose ends point in the upwind direction. Finally, if there is abundant sand and a strong, steady wind, the sand streams into *longitudinal dunes*, whose axis lies parallel to the wind direction.

In a sand dune, sand saltates up the windward side of the dune, blows over the crest of the dune, and then settles on the steeper, lee face of the dune. The slope of this face attains the angle of repose, the slope angle of a freestanding

FIGURE 17.14 Desert pavement, and a hypothesis for how it forms by building up a soil from below.

(a) A well-developed desert pavement in the Sonoran Desert, Arizona.

(b) Students standing at the edge of a trench cut into desert pavement. Note the soil between the pavement and the underlying alluvium.



(c) Desert pavement forms in stages. First, loose pebbles and cobbles collect at the surface. Dust settles among the stones and builds up a soil layer below. The stones eventually crack into smaller pieces and settle to form a mosaic-like pavement.

pile of sand. As sand collects on this surface, it eventually becomes unstable and slides down the slope, so geologists refer to the lee side of a dune as the *slip face*. As more and more sand accumulates on the slip face, the crest of the dune migrates downwind, and former slip faces become preserved inside the dune. In cross section, these slip faces appear as cross beds (**Fig. 17.15b, c**).

Take-Home Message

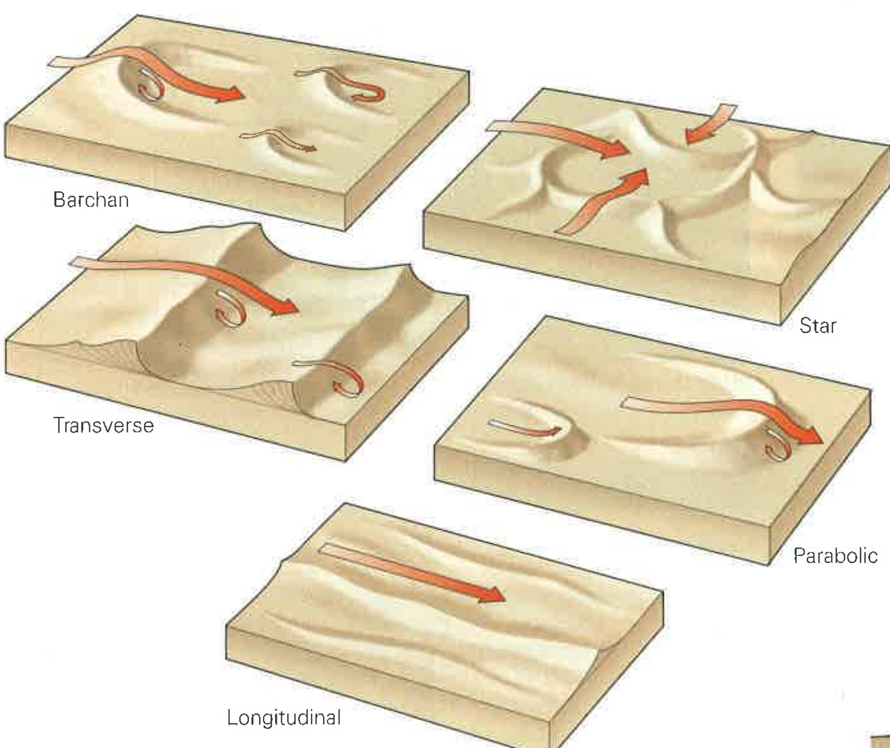
Erosion of thick layers of horizontal sedimentary rock in deserts yields buttes and mesas; erosion of tilted layers forms cuestas. Stony plains develop if finer sediment blows or washes away; some become desert pavements. Sandy areas contain many types of dunes.

17.6 Desert Problems

Natural droughts (periods of unusually low rainfall), overpopulation, overgrazing, careless agricultural practices, and diversion of water supplies have transformed semiarid grasslands into deserts in a matter of years to decades. The consequences of such **desertification** have, for example, devastated the Sahel, the belt of semiarid grassland that fringes the southern margin of the Sahara. In the past, the Sahel provided sufficient vegetation to support a small population of nomadic people and animals. But during the second half of the 20th century, large numbers of people migrated into the Sahel to escape overcrowding in central Africa. The immigrants began farming and maintained large herds of cattle and goats. As a consequence, plowing and overgrazing removed soil-preserving grass and caused the soil to dry out. In addition, the trampling of animal hooves compacted the ground so it could no longer soak up water. In the 1960s and again in the 1980s, a series of natural droughts hit the region, bringing catastrophe (**Fig. 17.16a, b**). Wind erosion stripped off the remaining topsoil. Without vegetation, the air grew drier, and the semiarid grassland of the Sahel became desert and its inhabitants endured a terrible famine.

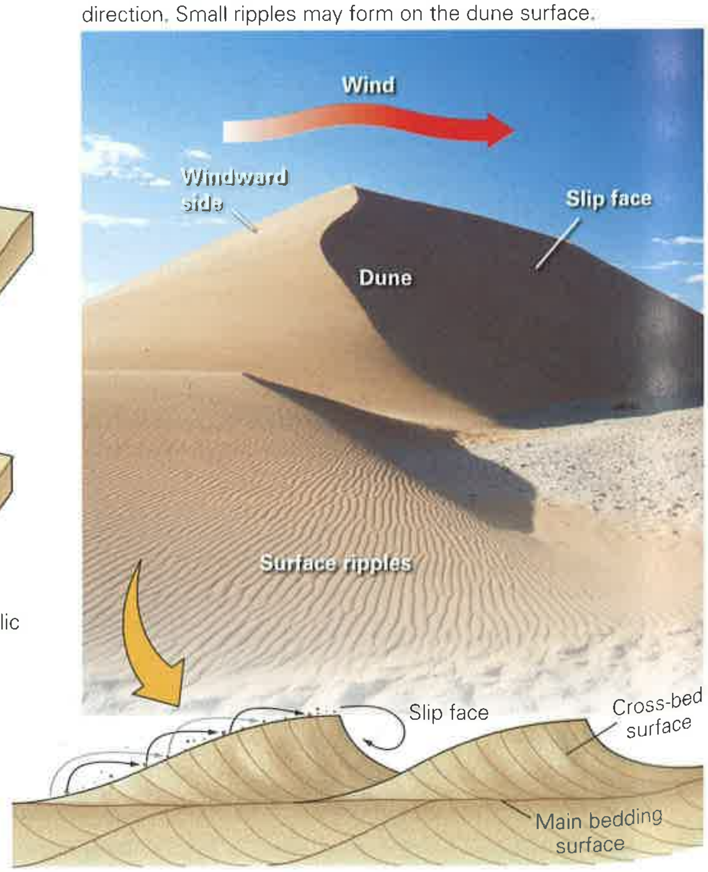
Desertification does not happen only in less industrialized nations. People in the western Great Plains of the United States and Canada suffered from the problem beginning in 1933, the fourth year of the Great Depression. Banks had failed, workers had lost their jobs, the stock market had crashed, and hardship burdened all. No one needed yet another disaster—but that year, even nature turned hostile. All through the fall, so little rain fell in the plains of Texas and Oklahoma that the region's grasslands and croplands browned and withered, and the topsoil turned to powdery dust. Then, on November 12

FIGURE 17.15 The types of sand dunes and the cross beds within them.



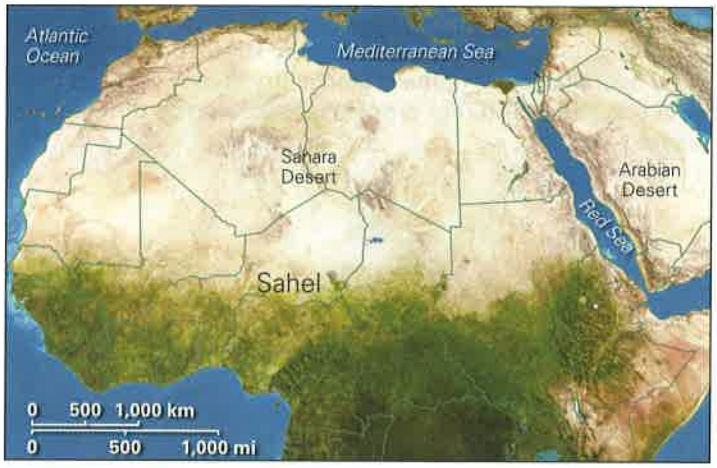
(a) The various kinds of sand dunes. Shapes depend on the sand supply and the wind character.

(b) The shape of a sand dune depends on the wind direction. Small ripples may form on the dune surface.



(c) Cross bedding inside a dune. Note that a cross bed is a buried slip face.

FIGURE 17.16 Desertification is happening in parts of Africa.



(a) The Sahel is the semi arid land along the southern edge of the Sahara. Large parts have undergone desertification.

(b) Drought in the Sahel has brought deadly consequences. Here, residents seek water from a dwindling pond.

and 13, strong storms blew eastward across the plains. Without vegetation to protect the ground, the wind stripped off the topsoil and sent it skyward to form rolling black clouds that literally blotted out the sun. People caught in the resulting dust storm found themselves gasping for breath. When the dust finally settled, it had buried houses and roads under huge drifts, and dirtied every nook and cranny. The dust blew east as far as New England, where it turned the snow brown. What had once been a rich farmland in the southwestern plains turned into a wasteland that soon acquired a nickname, the Dust Bowl. And it stayed this way for years.

Why did the fertile soils of the southern Great Plains suddenly dry up? The causes were complex; some were natural and some were human-induced. Typically, the region has a semiarid climate in which only thin soil develops. But the plains were settled in the 1880s and 1890s, which were unusually wet years. Not realizing its true character, far more people moved into the region than it could sustain, and the land was farmed too intensively. Plowing destroyed the fragile grassland root systems that held the thin soil in place. And when the drought of the 1930s came, it brought catastrophe.

Desertification has an additional dangerous side effect—global transmission of chemicals and pathogens by blowing dust. As desert areas expand in response to desertification, and as desert pavement gets disrupted, windblown dust becomes more of a problem. Dust blown off the Sahara can traverse the Atlantic and settle over the Caribbean (**Fig. 17.17**). Geologists are concerned that this dust, along with the fungi, toxic chemicals, and microbes that it carries, may infect corals with disease or in some other way inhibit their life processes. Thus, windblown dust can contribute to the destruction of coral reefs.

The Dust Bowl of the 1930s and the fate of the Sahel in Africa remind us how fragile the Earth's green blanket of vegetation really is. Global climate changes can shift climatic belts sufficiently to transform agricultural regions into deserts. Unfortunately, if the current trends in climate change continue, present-day agricultural belts could someday become new Saharas.

Take-Home Message

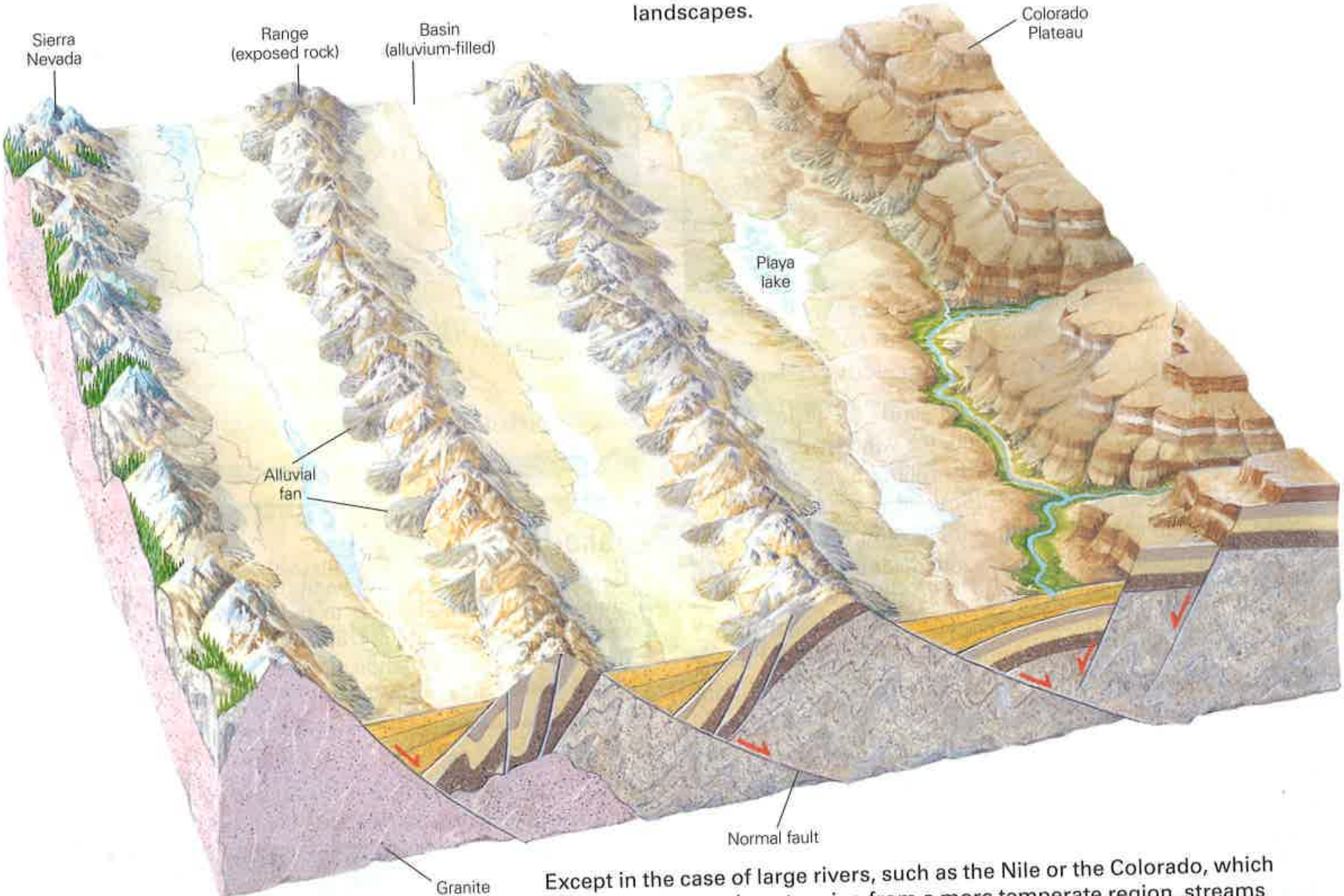
Desert populations have been burgeoning, so water supplies are problematic. In lands bordering deserts, droughts and population pressures have led to desertification, the transformation of vegetated land into desert. Dust storms can destroy topsoil.

FIGURE 17.17 In this satellite image, a huge dust cloud that originated in the Sahara blows across the Atlantic.

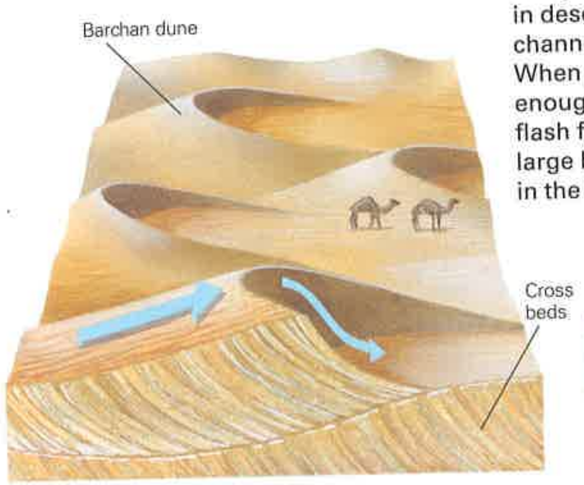
GEOLOGY AT A GLANCE

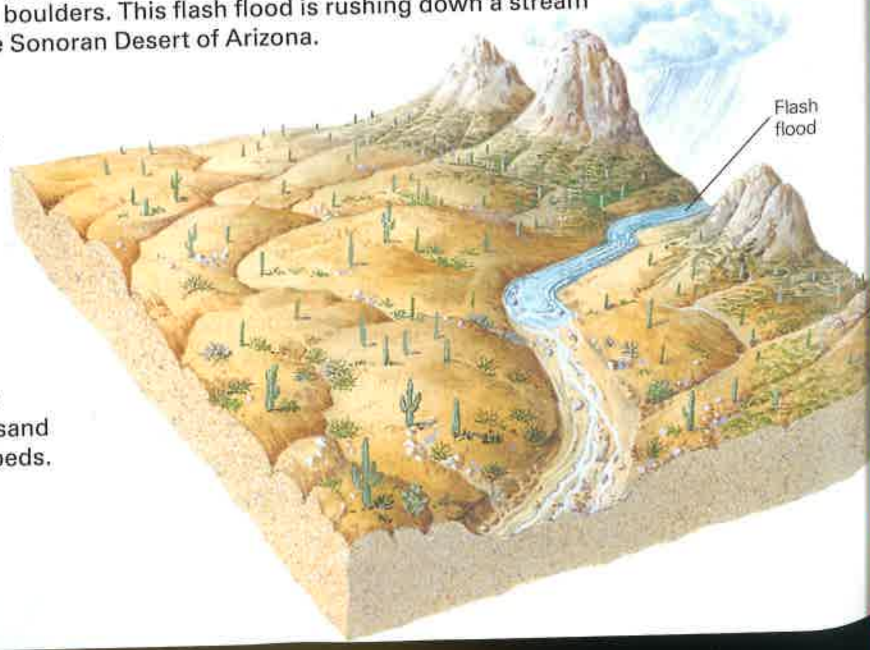
The Desert Realm

The desert of the Basin and Range Province in Utah, Nevada, and Arizona consists of alternating basins (grabens or half-grabens) separated by narrow ranges (tilted fault blocks). The Sierra Nevada, underlain largely by granite, borders the western edge of the province, while the Colorado Plateau, underlain by flat-lying sedimentary strata, borders the eastern edge. The overall climate of the region is dry. Because of the great variety of elevations and rock types, the region hosts different desert landscapes.



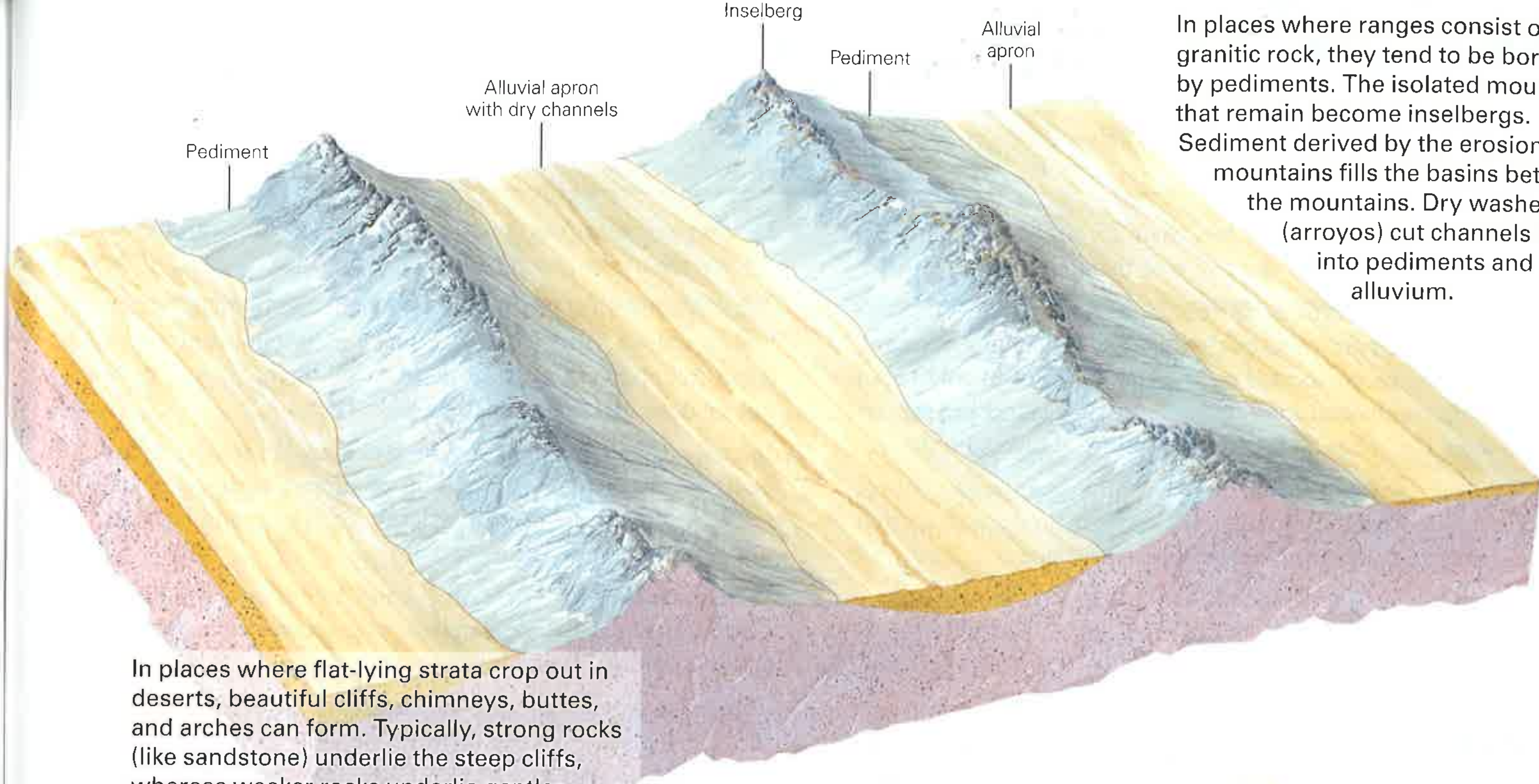
Except in the case of large rivers, such as the Nile or the Colorado, which bring water into a desert region from a more temperate region, streams in deserts fill with water only after heavy rains. At other times, the stream channels are dry. These channels are called dry washes, arroyos, or wadis. When there is a heavy rain, water cannot be absorbed into the ground fast enough, so runoff enters dry washes and fills them very quickly, creating a flash flood. The turbulent, muddy water of a flash flood can transport even large boulders. This flash flood is rushing down a stream in the Sonoran Desert of Arizona.



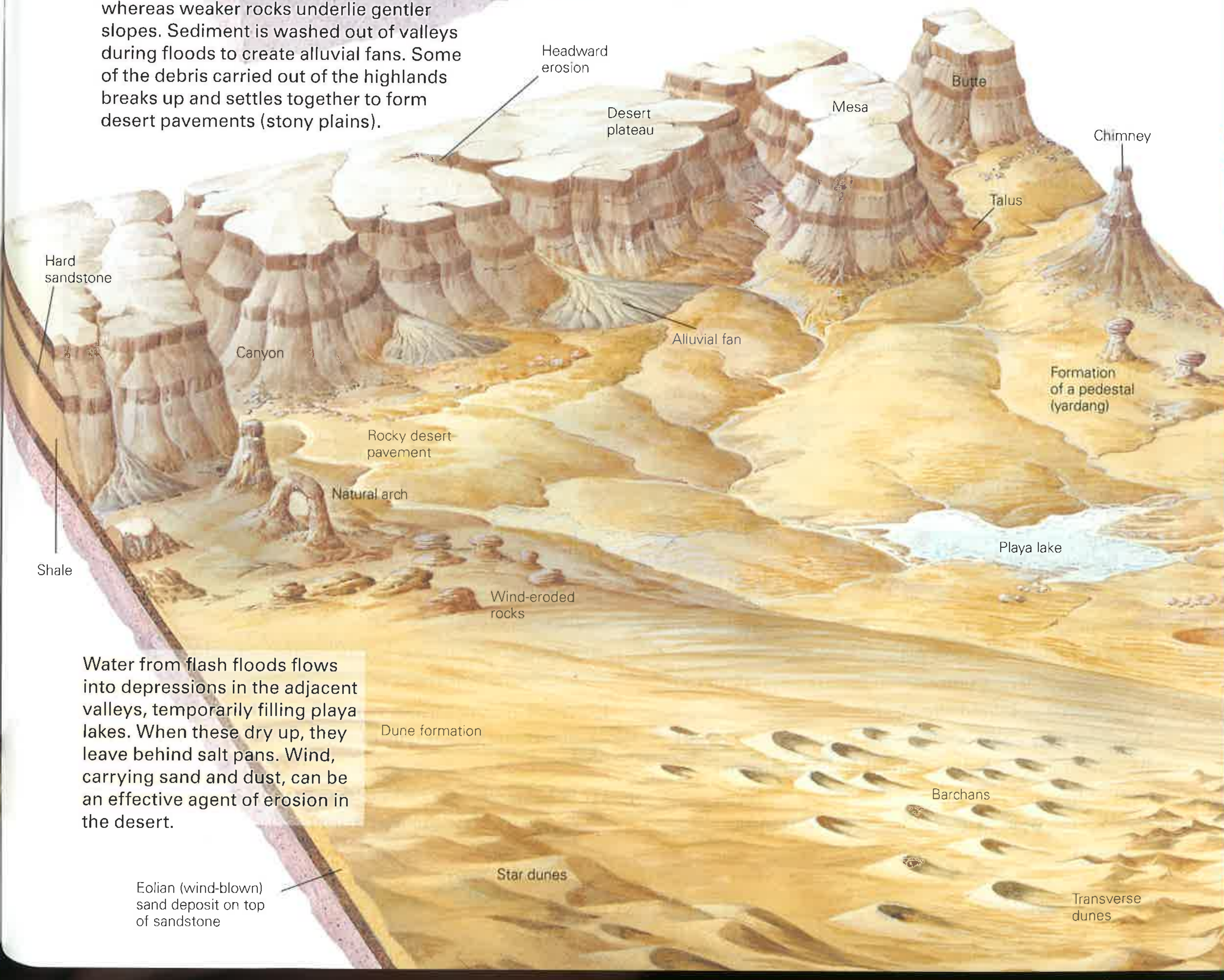


Where there is a large supply of sand, a variety of sand dunes develop. The geometry of a particular sand dune (such as barchan, longitudinal, or star) depends on the sand supply and the wind. Inside sand dunes, we find cross beds.

In places where ranges consist of granitic rock, they tend to be bordered by pediments. The isolated mountains that remain become inselbergs. Sediment derived by the erosion of the mountains fills the basins between the mountains. Dry washes (arroyos) cut channels both into pediments and alluvium.



In places where flat-lying strata crop out in deserts, beautiful cliffs, chimneys, buttes, and arches can form. Typically, strong rocks (like sandstone) underlie the steep cliffs, whereas weaker rocks underlie gentler slopes. Sediment is washed out of valleys during floods to create alluvial fans. Some of the debris carried out of the highlands breaks up and settles together to form desert pavements (stony plains).



Water from flash floods flows into depressions in the adjacent valleys, temporarily filling playa lakes. When these dry up, they leave behind salt pans. Wind, carrying sand and dust, can be an effective agent of erosion in the desert.

CHAPTER 17 REVIEW

Chapter Summary

- Deserts generally receive less than 25 cm of rain per year. Vegetation covers less than 15% of their surface.
- Subtropical deserts form between latitudes of 20° and 30°, rain-shadow deserts are found on the inland side of mountain ranges, coastal deserts are located on the land adjacent to cold ocean currents, continental-interior deserts exist in landlocked regions far from the ocean, and polar deserts form at high latitudes.
- Physical weathering in deserts produces rocky debris. Chemical weathering happens slowly; it produces ions that precipitate as new minerals below the surface.
- Water causes significant erosion in deserts, mostly during heavy downpours. Flash floods carry large quantities of sediments down ephemeral streams. When rain stops, streams dry up, leaving steep-sided dry washes.
- Wind picks up dust and silt as suspended load, and it causes sand to saltate. Where wind blows away finer sediment, a lag deposit remains. Windblown sediment abrades the ground, creating a variety of features such as ventifacts.
- Desert pavements are mosaics of varnished stones armoring the surface of the ground.
- Talus aprons form when rock fragments accumulate at the base of a slope. Alluvial fans form at a mountain front where water in ephemeral streams deposits sediment. When temporary desert lakes dry up, they leave playas.
- In some desert landscapes, erosion causes cliff retreat, eventually resulting in the formation of mesas, buttes, and inselbergs. Pediments of nearly flat or gently sloping bedrock surround some inselbergs.
- Where sand is abundant, the wind builds it into dunes. Common types include barchan, star, transverse, parabolic, and longitudinal (seif) dunes.
- Changing climates and land abuse may cause desertification, the transformation of semiarid land into deserts. Windblown dust, sometimes carrying microbes and toxins, may waft from deserts across oceans.

Key Terms

alluvial fan (p. 503)
arroyo (p. 501)
butte (p. 505)
chimney (p. 505)
cliff retreat (p. 505)
deflation (p. 502)
desert (p. 498)
desertification (p. 508)
desert pavement (p. 506)
desert varnish (p. 500)
dry wash (p. 501)
dune (p. 504)
dust storm (p. 502)
inselberg (p. 505)
lag deposit (p. 502)
mesa (p. 505)
pediment (p. 507)
petroglyph (p. 500)
playa (p. 504)
rain shadow (p. 498)
saltation (p. 502)
sand dune (p. 507)
surface load (p. 502)
suspended load (p. 502)
talus (p. 503)
ventifact (p. 502)

Review Questions

1. What factors determine whether a region can be classified as a desert?
2. Explain why deserts form.
3. Have today's deserts always been deserts? (*Hint*: Keep in mind the consequences of plate tectonics.)
4. How do weathering processes in deserts differ from those in temperate or humid climates?
5. Describe how water modifies the landscape of a desert. Be sure to discuss both erosional and depositional landforms.
6. Explain the ways in which desert winds transport sediment.
7. Explain how the following features form: (a) desert varnish; (b) desert pavement; (c) ventifacts.
8. Describe the process of formation of alluvial fans, bajadas, and playas.
9. Describe the process of cliff (scarp) retreat and the landforms that result from it.
10. What are the various types of sand dunes? What factors determine which type of dune develops at a particular location?
11. What is the process of desertification, and what causes it? How can desertification in Africa affect the Caribbean?