medium to fine sandstone with a few conglomerate and mudstone beds. The formation is made up of six multilateral, multistory sandstone sheet complexes, which are the main architectural units that build up the sheetlike sandstone formation. Most of the sandstone units display planar or trough cross-bedding. Some are marked by rippled surfaces, and a few are parallel laminated. Plant remains are scattered through the formation. The Cañizar Formation is interpreted as the deposits of a braided-river system with dominant bedload transport. The main facies formed as channel transverse bars, composite bars, and sandflat complexes. Lateral accretion was common on the bars.

The Buntsandstein facies as a whole displays gradation upward from coarse, braided-river deposits (Boniches Formation) through multistory, meandering-river sand bodies enclosed in floodplain muds (Alcotas Formation), to multistory sand sheets deposited in a braided-river system. The fluvial system flowed southeast through an asymmetrical graben (the Iberian Basin) in central Spain.

8.3 EOLIAN DESERT SYSTEMS

Introduction

Deserts cover broad areas of the world today, particularly within the latitudinal belts of about 10–30 degrees north and south of the equator, where dry, descending air masses create prevailing wind systems that sweep toward the equator. Deserts also lie in the interiors of continents and in the rain shadows of large mountain ranges where they are cut off from moisture from the oceans. Deserts are areas in which potential rates of evaporation greatly exceed rates of precipitation. They cover about 20–25 percent of the present land surface.

Because of their generally low rainfall, commonly less than about 25 cm/yr, we tend to think of deserts as extremely dry areas dominated by wind activity and covered by sand. In reality, a variety of subenvironments exist within deserts, such as alluvial fans; ephemeral streams that run intermittently in response to occasional rains; ephemeral saline lakes, also called playas or inland sabkhas; sand-dune fields; interdune areas covered by sediments, bare rocks, or deflation pavement; and areas around the fringe of deserts where windblown dust (loess) accumulates. Large areas of the desert environment may indeed be carpeted by windblown, or **eolian**, sand. Such areas that cover more than about 125 km^2 are called **sand seas** or **ergs** (Fig. 8.14); smaller areas are called **dune fields**. Ergs and dune fields cover about 20 percent of modern deserts or about 6 percent of the global land surface. The remaining areas of deserts are covered by eroding mountains, rocky areas, and desert flats. The largest desert in the world, the Sahara (7 million km^2), contains several ergs arranged in belts. The larger belts cover areas as extensive as 500,000 km^2.

Transport and Depositional Processes in Deserts

Most deserts are characterized by extreme fluctuations in temperature and wind, on both a daily and a seasonal basis. Rainfall rates are low, as mentioned, and the rains are very sporadic. Vegetation is generally extremely sparse. When rains do come, they tend, owing to the lack of vegetative cover, to create flash floods. Rainwater typically drains toward the centers of desert basins, where playas or inland sabkhas may develop and become sites of deposition of carbonate and evaporite minerals. Because periodic rains create flash floods and ephemeral streams and mobilize debris flows and mudflows, they are extremely important agents of sediment transport in deserts. Nonetheless, much of the time water plays a relatively small role in sediment transport in deserts. Most of time, wind is the dominant

Figure 8.14
Spaceborne radar image of part of the vast Namib Sand Sea on the west coast of southern Africa, just northeast of the city of Luderitz, Namibia, showing a variety of dune shapes and sizes. NASA image acquired by spaceborne imaging radar on board the space shuttle Endeavour, April 11, 1994. Downloaded from the Web 1/13/2000.

agent of sediment transport and deposition. Wind is much less effective than water as an agent of erosion, but it is an extremely effective medium of transport for loose sand and finer sediment. Not only does it account for the transport of vast quantities of siliciclastic sand in deserts, but it is also responsible for sediment transport in glacial environments, on river flood plains, and along many coastal areas, where both carbonate and siliciclastic sands may be transported inland. The windblown deposits of these latter environments are quite small compared to the sand seas of desert areas. Wind storms, or dust storms, may also carry silt and clay far from their sources and are responsible for transporting much of the pelagic sediment to deep ocean basins.

Wind transports sediment in much the same way as water, separating the sediment into three transport populations: traction, saltation, and suspension. Transport of grains by wind is initiated when wind strength rises to the fluid threshold and also when wind blowing at greater than threshold speed over an immobile surface encounters the leading edge of a deposit of loose, mobile material. Direct dislodgment by wind may also play a role in grain transport (Anderson, Sorenson, and Willets, 1991). Grain motion appears to cascade rapidly as those grains most susceptible to direct dislodgment collide (downwind) with and disturb less susceptible grains. The rapidity of the dislodgment depends upon the grain size, shape, sorting, and packing. At scattered locations, almost random, near-bed turbulence causes the wind flow to be seeded with low-energy ejected grains. Many of these grains translate downwind at a range of speeds, dislodging other grains as they go. A single flurry, therefore, tends to give rise to a translating and dispersing sequence of dislodgments. At a particular locality undergoing threshold wind flow, many such dislodgment sequences may be superimposed to produce overall entrainment and transport.

Wind effectively separates sediment finer than about 0.05 mm from coarser sediment and transports this fine sediment long distances in suspension. Except at unusually high wind velocities, coarser sediment travels by traction and saltation close to the ground. Saltation is a particularly important mode of wind transport, aided by downslope creep of grains owing to the impact of saltating grains as they strike the bed. Wind appears to be especially effective in transport of medium to fine sand and finer sediment, but coarse particles (up to 2 mm or somewhat larger) may also undergo transport by rolling and surface creep under high-velocity winds. The transporting and sorting action of wind tends to produce three kinds of deposits: dust (silt) deposits, sometimes referred to as **loess**, that commonly accumulate far from the source; sand deposits, which are commonly well sorted; and lag deposits, consisting of gravel-size particles that are too large to be transported by wind and that form a **deflation pavement.**

Wind transport and deposition generates many of the same kinds of bedforms and sedimentary structures—such as ripples, dunes, and cross-beds—as those produced by water transport. The bedforms that develop during wind transport range from ripples as small as 0.01 m long and a few millimeters in height to dunes 500–600 m long and 100 m high. Less commonly, gigantic bedforms called **draas** that may have wavelengths measured in kilometers (up to 5.5 km) and heights up to 400 m may also form by wind transport (Wilson, 1972; McKee, 1982). The wave length of wind-transported bedforms increases with increasing wind velocity, and wave height tends to increase with increasing grain size. Under a given set of conditions of grain size and wind velocity, ripples, dunes, and draas can coexist. Thus, dunes exist on the backs of draas, and ripples are created on the backs of dunes.

Bagnold's (1954) study dealing with the physics of blown sand remains the classic piece of research in the field of eolian sediment transport and deposition; however, more recent workers continue to investigate this subject (e.g., Barndorff-Nielsen and Willets, 1991; McEwan and Willets, 1993; Gilette, 1999). An interesting research trend is the use of computer modeling and simulation to generate data that can be compared to experimental observations from field and wind tunnel (e.g., McEwan and Willets, 1993).

Deposits of Modern Deserts

Eolian sediments accumulate in a variety of small-scale settings in deserts and even in shoreline environments; however, the major areas of accumulation are in **ergs** (sand seas). Ergs form under prevailing wind systems, primarily in arid regions, where copious supplies of fine sediment are present. Noteworthy present-day ergs include those of the Saharan and Arabian deserts of northern Africa, the Namib Desert of southern Africa (Fig. 8.14), the Mojave and Sonoran deserts of southwestern North America, and the Australian Desert of central Australia. Sediment supply, availability, and wind energy play major roles in determining the geomorphology of ergs. Dune patterns in sand seas are the product of (1) regional changes in wind regimes that promote the formation of dunes of different morphological types, and (2) temporal changes in sand supply, availability, and mobility that give rise to the generation of multiple episodes of dune formation (Lancaster, 1999).

The various environments of deserts can be grouped into three main subenvironments: dune, interdune, and sand sheet (Ahlbrandt and Fryberger, 1982; Fig. 8.15). The dune environment is primarily the site of wind transport and deposition of sand, which accumulates in a variety of dune forms, many having steeply dipping slip faces or avalanche faces. Interdune areas can receive both windblown sediment and sediment transported and deposited by ephemeral streams in stream floodplains or playa lakes. The sheet-sand environment exists around the margins of dune fields. The deposits of this environment form a transitional facies between dune and interdune deposits and deposits of other environments.

Dunes

Many types of dunes (e.g., Fig. 8.16) occur in the sand seas and dune fields of modern deserts, ranging from those with no slip faces to those with three or more

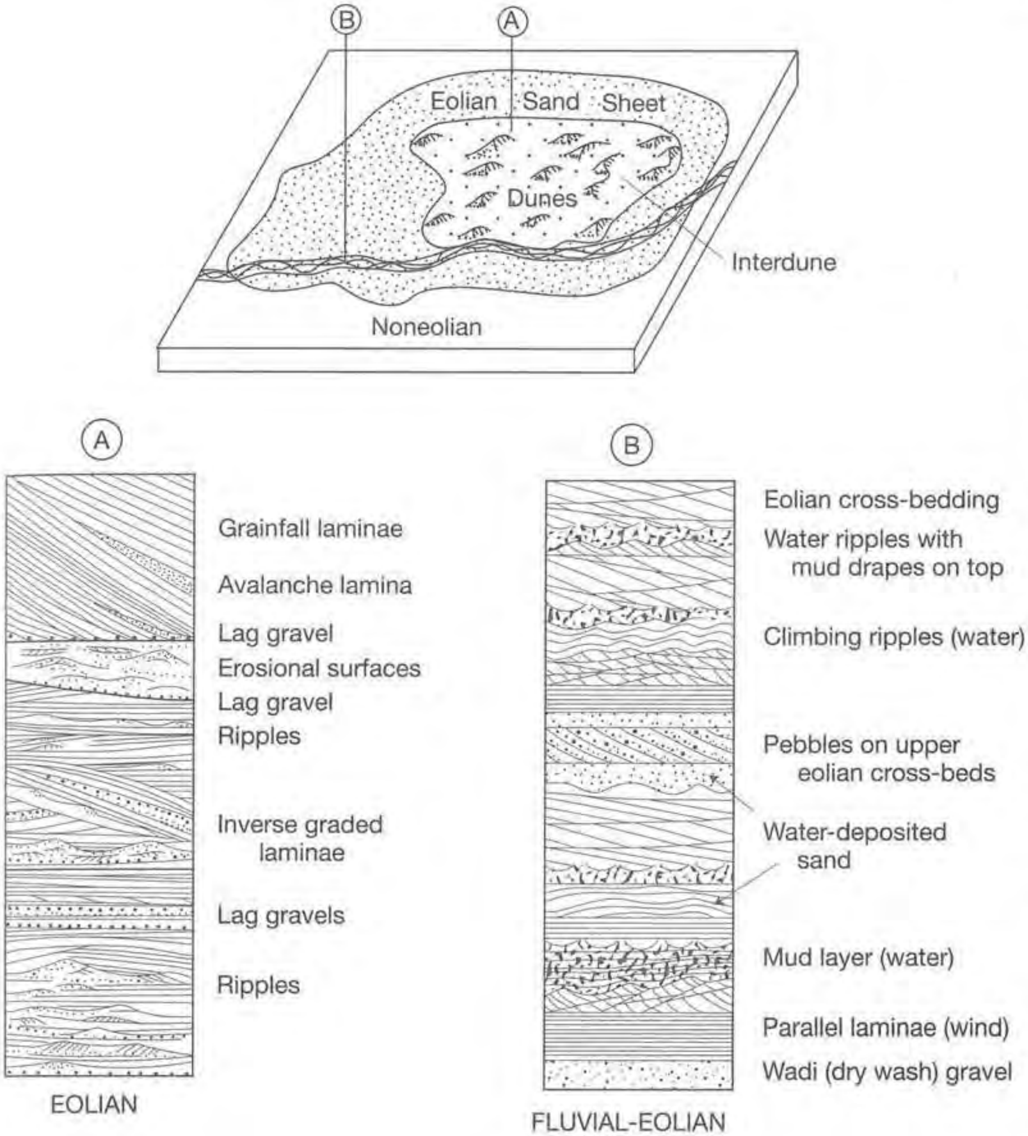

Figure 8.15
Areal distribution and stratigraphic relationships of sheet sands and eolian dune sands. Column A shows cross-lamination and other typical bedding features, including lag gravels on erosional surfaces, in an eolian succession deposited in a dune environment. Column B depicts a fluvial-eolian succession formed in an eolian sand-sheet environment. [After Fryberger, S. G., T. S. Ahlbrandt, and S. Andrews, 1979, Origin, sedimentary features, and significance of low-angle eolian "sand sheet" deposits, Great Sand Dunes National Monument and vicinity, Colorado: Jour. Sed. Petrology, v. 49, Fig. 12, p. 745, reprinted by permission of Society of Economic Paleontologists and Mineralogists, Tulsa, Okla.]

Figure 8.16
Sand dunes near Stovepipe Wells, Death Valley, California. Note the sharply developed slip facies, indicating sand transport from left to right. Photograph by James Stovall.

slip faces (Fig. 8.17). Eolian bedforms range in scale from small ripples to transverse and longitudinal dunes 0.1 to 100 m high to complex dunes, called draas, with heights of 20 to 450 m. Dune morphology is determined by the availability of sand, wind intensity, and the variability of wind directions (e.g., Lancaster, 1999; Pye and Tsoar, 1990, Chapter 6).

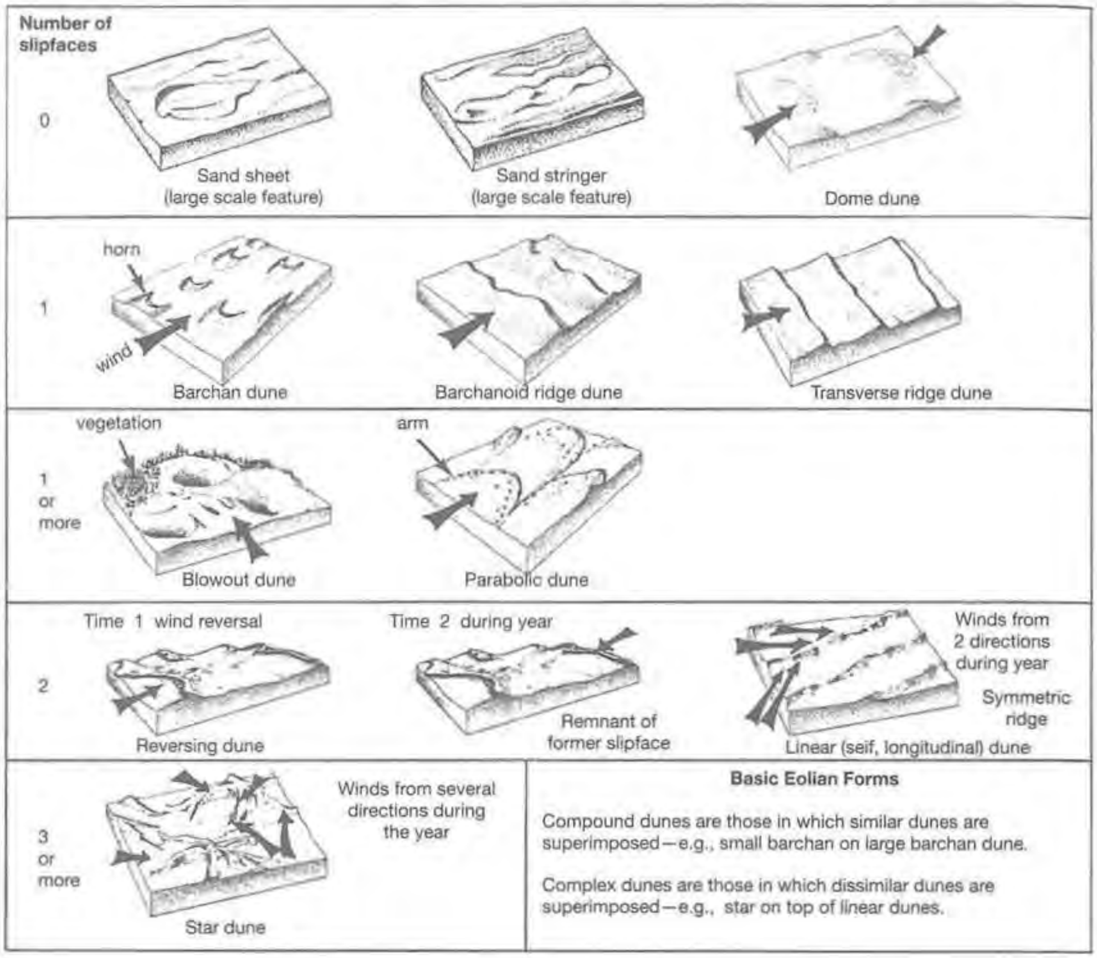

Figure 8.17
Basic eolian dune forms grouped by number of slip faces. [After Ahlbrandt, T. S., and S. G. Fryberger, 1982, Introduction to eolian deposits, in Scholle, P. A., and D. Spearing (eds.), Sandstone depositional environments: Am. Assoc. Petroleum Geologists Mem. 31, Fig. 3, p. 14, reprinted by permission of AAPG, Tulsa, Okla.]

Dune deposits commonly consist of texturally mature sands that are well sorted and well rounded; however, considerable textural variation can occur. They are also typically quartz rich, although many coastal dune deposits contain high concentrations of heavy minerals and unstable rock fragments. Coastal dunes in some tropical areas may consist largely of ooids, skeletal fragments, or other carbonate grains, and dunes composed of gypsum occur in some desert areas, such as White Sands, New Mexico. Eolian dunes are characterized particularly by large-scale cross-bedding (e.g., Fig. 4.18). Several kinds of small-scale internal structures may also be present, such as plane-bed laminae, rippleform laminae, ripple-foreset cross-laminae, climbing ripples, grainfall laminae, and sandflow cross-strata (e.g., Hunter, 1977). Migration of dunes generates a vertical succession of sandy facies that may display many of these structures (e.g., Fig. 8.15).

Owing to the variety of dune types that can form under different wind conditions, local paleocurrent vectors derived from eolian cross-bed data can range from unimodal to polymodal. Paleocurrent data may thus show a high degree of scatter that complicates calculation of ancient prevailing sediment transport directions. On a regional scale, eolian paleocurrent patterns are reported to swing over hundreds of miles around high-pressure wind systems.

Interdunes

Interdune areas occur between dunes and are bounded by dunes or other eolian deposits such as sand sheets (Fig. 8.15). Interdunes may be either deflationary (erosional) or depositional. Very little sediment accumulates in most deflationary interdunes except coarse, granule-size lag sediments that may show rippled surfaces and inverse grading. Deflationary interdunes are preserved in the rock record as a disconformity overlain by thin, discontinuous, winnowed lag deposits. Sediments deposited in depositional interdunes can include both subaqueous and subaerial deposits depending upon whether they are deposited in wet, dry, or evaporite interdunes (Ahlbrandt and Fryberger, 1981). All interdune deposits are characterized by low-angle stratification ($<\sim10°$), because they are formed by processes other than dune migration, although many deposits may be almost structureless owing to secondary processes, largely bioturbation, that destroy stratification.

Dry interdunes or interdunes that are wetted only occasionally are most common. Deposits in dry interdunes are generated by ripple-related wind-transport processes, grainfall in the wind shadow in the lee of dunes, or sandflow (avalanching) from adjacent dunes. The deposits tend to be relatively coarse, bimodal, and poorly sorted, with gently dipping, poorly laminated layers. They are also commonly extensively bioturbated by both animals and plants.

Wet interdune areas are the sites of lakes or ponds where silts and clays are trapped by semipermanent standing bodies of water rather than being deflated and removed. These sediments may contain freshwater species of organisms such as gastropods, pelecypods, diatoms, and ostracods. They are also commonly bioturbated and may contain vertebrate footprints. Some wet interdune sediments become contorted owing to loading by dune sediments.

Evaporite interdunes, or inland sabkhas, occur where drying of shallow ephemeral lakes or evaporation of damp surfaces causes precipitation of carbonate minerals, gypsum, or anhydrite. Growth of carbonate minerals or gypsum in sandy sediment tends to disrupt and modify primary depositional features. Desiccation cracks, raindrop imprints, evaporite layers, and pseudomorphs may characterize these sediments (e.g., Lancaster and Teller, 1988).

Sheet Sands

Sheet sands are flat to gently undulating bodies of sand that commonly surround dune fields. They are typically characterized by low to moderately dipping (0–20°) cross-stratification and may be interbedded in some parts with ephemeral stream deposits (Fig. 8.15). Sheet-sand deposits may also contain gently dipping, curved, or irregular surfaces of erosion several meters in length; abundant bioturbation traces formed by insects and plants; small-scale cut-and-fill structures; gently dipping, poorly laminated layers resulting from adjacent grainfall deposition; discontinuous, thin layers of coarse sand intercalated with fine sand; and occasional intercalations of high-angle eolian deposits (e.g., Ahlbrandt and Fryberger, 1982; Kocurek and Nielson, 1986; Schwan, 1988).

Kinds of Eolian Systems

Desert systems can be characterized as wet, dry, or stabilized (Kocurek and Havholm, 1993; Kocurek, 1996). **Dry systems** are those in which the water table and its capillary fringe lie at depth below the depositional surface. Therefore, the water table has no stabilizing effect on the surface and near-surface sediment. The aerodynamic configuration or shape of the sediment surface (e.g., dune shape) alone determines whether sediment is deposited or simply moves across the surface (bypass) or, alternatively, if erosion of previously deposited sediment takes place. In **wet systems,** the water table or its capillary fringe is at or near the depositional surface. Therefore, deposition, bypass, and erosion along the substrate are controlled by the moisture content of the substrate as well as by its aerodynamic shape. **Stabilized systems** are those in which factors such as vegetation, surface cementation, or mud drapes play a significant stabilizing role and thus influence the behavior of the accumulating surface. Major eolian environments such as the Sahara may show a full range of these three kinds of eolian systems (Kocurek, 1996).

The extent to which eolian sediment is preserved to become part of the geologic record is strongly influenced by the kind of system in which it accumulates. The vertical space in which sediment accumulates is called its **accumulation space**; however, only that sediment which lies below the baseline of erosion is preserved (the **preservation space**). This baseline is affected mainly by subsidence (caused by tectonism, loading, and compaction) and the position of the water table. Not all of the sediment that accumulates in dry eolian systems may be preserved. Preservation can occur if subsidence brings the sediment below the erosional base level, the water table rises through the dry accumulation, or a combination of these two factors takes place (Kocurek, 1999; Fig. 8.18). In wet systems, the accumulation space is essentially also the preservation space because the water table is near the surface. In a stabilizing system, some preservation can occur above the regional baseline of erosion. Keep in mind, however, that as dunes migrate, the dune bedforms themselves (the shapes of the dunes) are not preserved. The depositional record that the migrating dunes leave behind is mainly the lower foresets only.

Bounding Surfaces in Eolian Deposits

As mentioned, bedforms are only rarely preserved in ancient eolian deposits. Instead, we see cross-bedding and other internal features (e.g., Fig. 8.15 A, B), mainly from the lowest parts of the original bedforms, that remain as a record of bedform migration across ancient deserts. In addition to foresets and other bedding features, several kinds of bounding surfaces may be generated within eolian successions as a record of complex depositional and erosional processes. Brookfield (1984) describes three kinds of bounding surfaces: flat, first-order surfaces related to migration of large bedforms; inclined, second-order surfaces that commonly slope downwind and enclose cosets of cross-strata deposited by smaller dunes superimposed on large bedforms; and third-order surfaces that are generated by erosional modification of the lee faces of migrating dunes.

Kocurek (1996) suggests that it is difficult to apply this hierarchical scheme of first-, second-, and third-order surfaces in surface sections and recommends abandoning the terminology. Instead, he proposes the following terminology for these surfaces: **reactivation or redefinition surfaces** (third-order), which occur because of periodic erosion of the lee faces of dunes; **superposition surfaces** (second-order), which form by migration of dunes or scour troughs superimposed

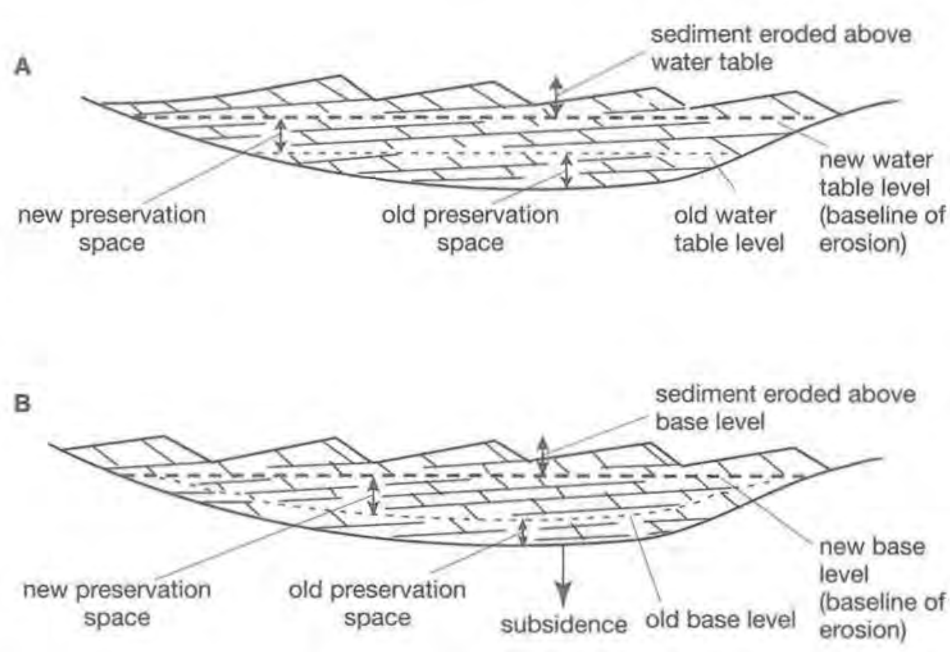

Figure 8.18
Examples of preservation of eolian sediment accumulations. A. New (increased) accumulation space created by a relative rise in the water table. B. Accumulation space created by subsidence below the baseline of erosion. [After Kocurek, G., and K. G. Havholm, 1993, Eolian sequence stratigraphy—A conceptual framework, in Weimer, P., and H. W. Posamentier (eds.), Siliciclastic sequence stratigraphy: Recent developments and applications: AAPG Memoir 58, Fig. 13, p. 405, reproduced by permission.]

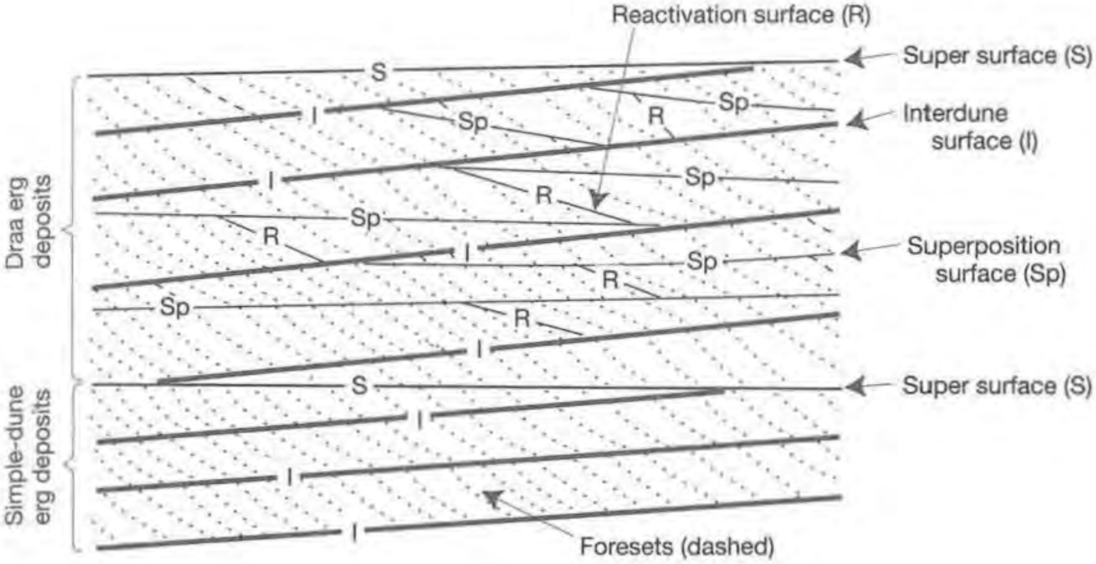

Figure 8.19
Bounding surfaces in eolian deposits. Note that superposition and reactivation surfaces are contained within cross-bed sets or cosets bounded by interdune surfaces, and that super surfaces (unconformities) can truncate interdune surfaces and entire erg successions. [Modified from Kocurek, G., 1988, First-order and super bounding surfaces in eolian sequences—Bounding surfaces revisited: Sedimentary Geology, v. 56, Fig. 2, p. 195, reproduced by permission of Elsevier Science Publishers.]

on the lee face of the main bedform; and **interdune surfaces** (first-order) formed between sets or cosets of cross-strata and that separate accumulations of the different bedforms (Fig. 8.19).

In addition to the above surfaces, regional unconformities may be present within eolian successions that mark the end of a major episode of eolian deposition. Such unconformities are referred to as **super surfaces** (Kocurek, 1996). They signify regional interruption of sand-sea deposition and develop in response to changes in sediment supply, climate, or possibly sea level in some cases. They may be surfaces of erosion, where sediment has deflated down to the water table, or surfaces of bypassing. On a bypassing surface, there is no net erosion or sediment accumulation. Sediment is simply transported across the surface to other areas.

Ancient Desert Deposits

Navajo/Nugget Sandstone

The Jurassic Navajo Formation of the southwestern United States is one of the thickest, most widespread, and best exposed ancient eolian (erg) depositional systems in the world (Kocurek, 2003). The Navajo, and its lateral equivalent Nugget Sandstone, reach nearly 700 m in thickness and extend over 265,000 km^2 over portions of five states (Fig. 8.20). The original extent of the Navajo sand seas was about 2.5 times as large as the present outcrop (Marzolf, 1988).

The Navajo has been suggested in the past to be a marine deposit; however, few geologists today doubt its eolian origin. Petrologically, it consists of fine- to medium-size quartz grains that are generally well rounded and commonly frosted. The most striking feature of the Navajo is the presence of huge tabular cross-bed sets that display sweeping foresets (Fig. 8.21). Dips of foresets commonly exceed 20°, and individual cross-bed sets range in thickness from about 5 m to almost 35 m. Freshwater invertebrate fossils (ostracods and crustaceans) have been reported from the Navajo, as well as dinosaur and pteropod tracks and skeletons of bipedal dinosaurs and early mammals. Slump structures such as contorted

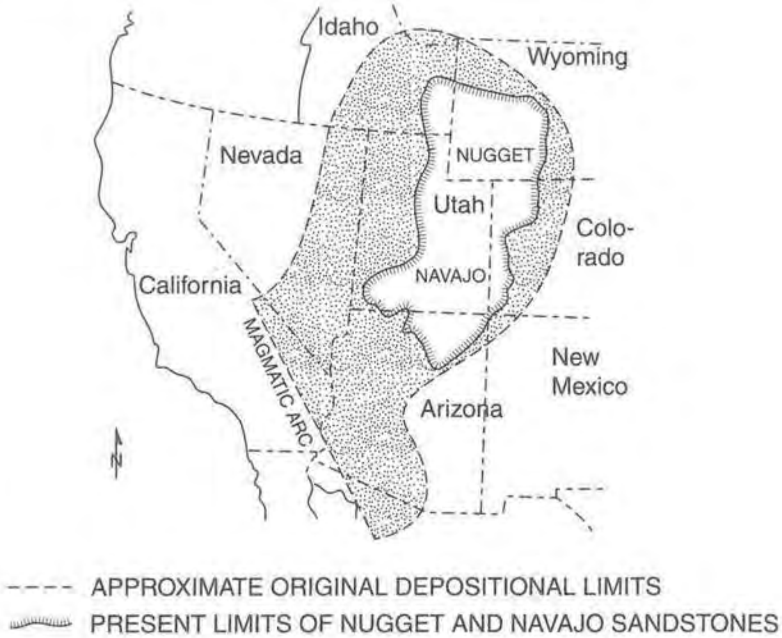

Figure 8.20
Estimates of the minimum and maximum areas of deposition of the Navajo Sandstone and its lateral equivalents. [After Marzolf, J. E., 1988, Controls on late Paleozoic and early Mesozoic deposition of the western United States: Sedimentary Geology, v. 56, Fig. 6, p. 179, reproduced by permission.]

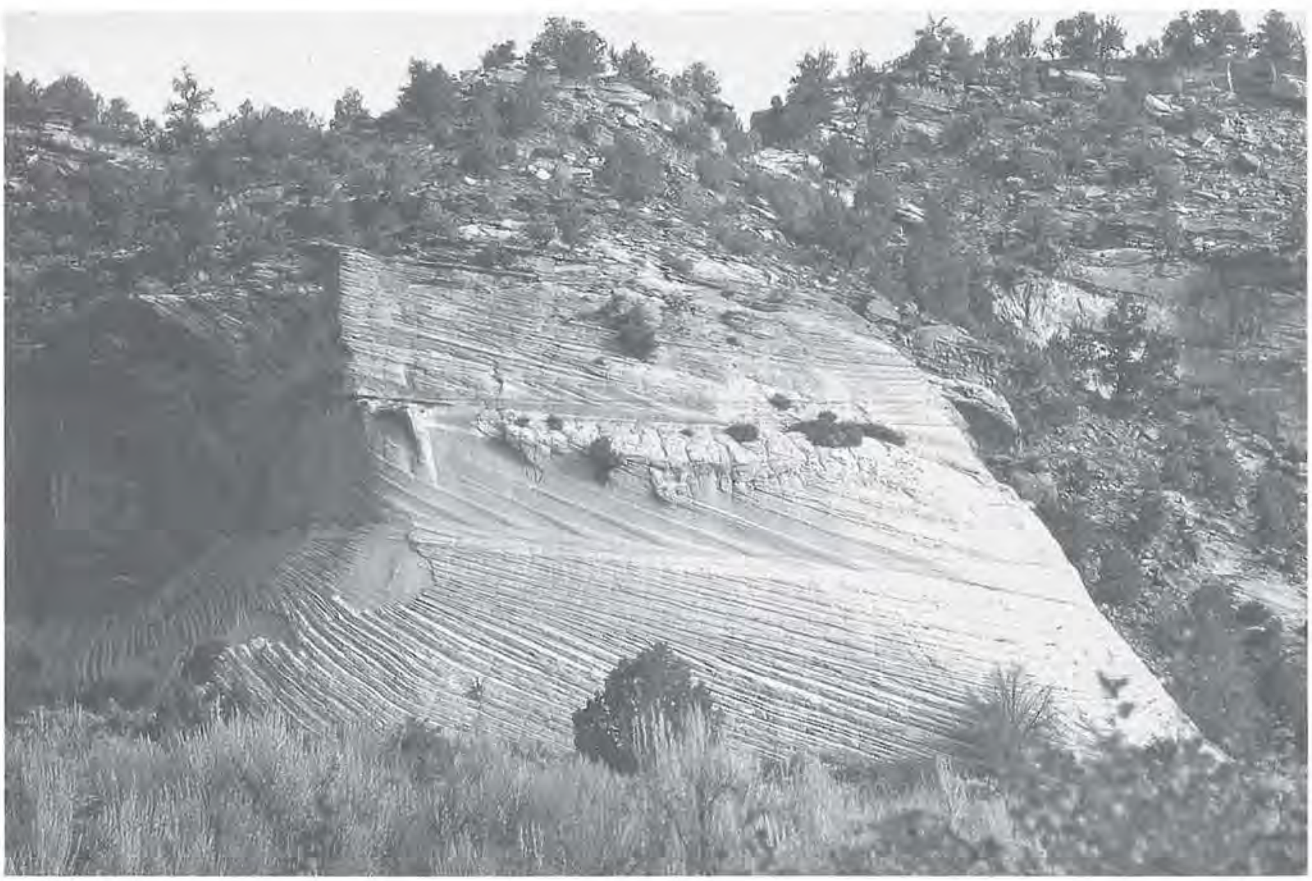

Figure 8.21
Navajo Sandstone (Jurassic) in Zion National Park, Utah, showing large sets of cross strata generated by migration from left to right of ancient eolian sand dunes. Note the prominent interdune bounding surfaces (see Fig. 8.19) between cross-bed sets.

bedding, which are reported from modern dune sands that have been wetted, are also common.

As described in preceding paragraphs, sediment deposited during migration of dunes across a desert may be preserved in part, commonly the lower part of the foresets, owing to rise in water table, basin subsidence, or both. Succeeding, successive migrations across a subsiding basin result in vertical stacking of eolian facies separated by interdune bounding surfaces and super surfaces. At the margins of dune fields, the boundary between eolian and other (e.g., fluvial or marine) environments may shift back and forth, generating a vertical succession of facies in which eolian and noneolian sediments are interbedded. For example, the schematic illustration in Figure 8.15 shows an eolian succession in Column A and an interbedded fluvial-eolian succession in Column B.

The Navajo Sandstone provides a real example of this principle, as shown by intertonguing eolian deposits of the Navajo and fluvial deposits of the Kayenta Formation in northeastern Arizona (Fig. 8.22). Three fluvial to eolian drying-upward cycles are illustrated, each representing the advance of the Navajo erg across the Kayenta alluvial plain, probably in response to an increasingly arid climate. Return to wetter conditions terminated the advance of the erg, allowing fluvial deposits of the Kayenta to, in turn, advance over an erosional Navajo surface. Thus, in this succession, cross-bedded Navajo eolian dune deposits and flooded interdune deposits are interbedded vertically with floodplain and other fluvial deposits of the Kayenta Formation.

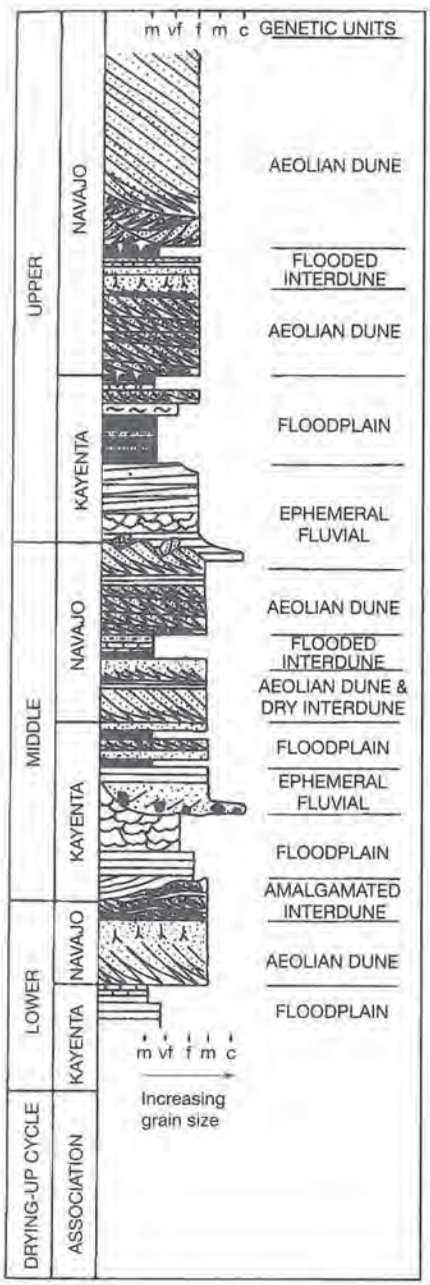

Figure 8.22
Representative intertonguing Jurassic eolian (Navajo) and fluvial (Kayenta) facies in northeastern Arizona. Total thickness of the column is about 100 m. Note three major drying-up cycles, indicating advance and retreat of the Navajo erg. [After Herries, R. D., 1993, Contrasting styles of fluvial-eolian interaction at a downwind erg margin: Jurassic Kayenta-Navajo transition, northeastern Arizona, *in* North, C. P., and D. J. Prosser (eds.), Characterization of fluvial and aeolian reservoirs, Geological Society London Special Publication No. 73, Fig. 17, p. 210, reproduced by permission.]

Other Ancient Desert Deposits

Ancient sandstones interpreted to be windblown deposits have been described from sedimentary successions as old as the Precambrian from many parts of the world. One of the most extensive and intensely studied eolian records is from the late Paleozoic and Mesozoic of the western interior of the United States (Blakey, Peterson, and Kocurek, 1988). In addition to the Navajo Sandstone, described above, eolian deposits are widespread from Montana to Arizona and include Pennsylvanian (e.g., Weber and Tensleep), Permian (e.g., Cedar Mesa and Coconino), Triassic (e.g., Jelm and Wingate), and Jurassic (Entrada) formations. This impressive eolian system consists of thick, extensive assemblages that represent deposition from different types of dunes and eolian complexes and interaction among eolian, fluvial, marine, and lacustrine environments.

Examples from other continents include the Permian Rotliegendes of northwestern Europe, the Jurassic-Cretaceous Botucatu Formation of the Parana Basin of Brazil, the Permian Lower Bunter Sandstone of Great Britain, the Permo-Triassic Hopeman Sandstone of Scotland, the Permian Corrie Sandstone of Scotland, and the Proterozoic (Precambrian) of India and northwestern Africa. The Rotliegendes has been particularly well studied (e.g., Glennie, 1986). It accumulated in a series of graben (fault) basins as interbedded eolian, fluvial, lacustrine (lake), and sabkha (evaporite) deposits, again illustrating the complex interaction of eolian and noneolian systems. Other examples of ancient eolian deposits can be found in "Further Reading—Eolian Systems" at the end of this chapter.

8.4 LACUSTRINE SYSTEMS

Lakes cover about 1–2 percent of Earth's surface. Because the world's continents are presently in a higher state of emergence than was typical of much of Phanerozoic time, lake sedimentation is more prevalent today than it was during much of the geologic past. In fact, ancient lake sediments appear to be of only minor importance volumetrically in the overall stratigraphic record, although they have been reported in stratigraphic successions ranging in age from Precambrian to Holocene. Although not abundant in the geologic record, lake sediments are nonetheless important. Lake chemistry is sensitive to climatic conditions, making lake sediments useful indicators of past climates. For example, several studies have shown that ancient episodes of wet and dry climates can be deciphered on the basis of lake sediment chemistry and mineralogy. Also, some lake deposits contain economically significant quantities of oil shales, evaporite minerals, coal, uranium, or iron. Many lake sediments also contain abundant fine organic matter that may act after burial as a source material for petroleum (Katz, 1990).

Origin and Size of Lakes

The basins, or depressions, in which lakes form can be created by a variety of mechanisms, including tectonic movements such as faulting and rifting; glacial processes such as ice scouring, ice damming, and moraine damming; landslides or other mass movements; volcanic activity such as lava damming or crater explosion and collapse; deflation by wind scour or damming by windblown sand; and fluvial activity such as the formation of oxbow lakes and levee lakes. Many existing lakes appear to have originated directly or indirectly by glacial processes (Picard and High, 1981) and thus may not be typical of ancient lakes, which formed predominantly by tectonic processes. On the other hand, we know that some large modern lakes also formed by tectonic processes (e.g., Lake Tanganyika in the East African rift system, Lake Baikal in the Baikel rift system in Siberia) and volcanic processes (e.g., Crater Lake, Oregon). Of the twenty-five largest lakes by surface