

Sand dunes

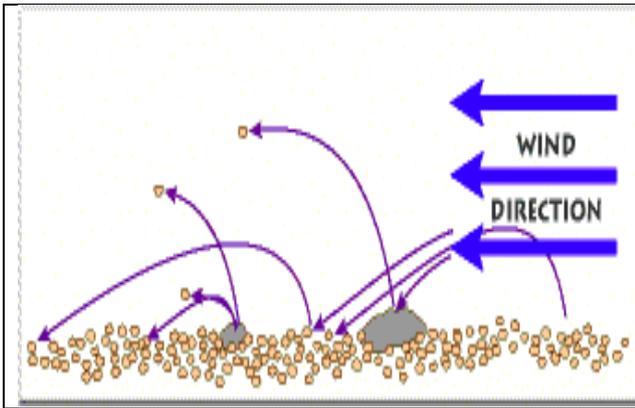
Introduction

A **dune** is a hill of loose sand built by aeolian processes (wind) or the flow of water. Dunes occur in different shapes and sizes, formed by interaction with the flow of air or water. Most kinds of dunes are longer on the stoss (upflow) side, where the sand is pushed up the dune, and have a shorter "slip face" in the lee side. The valley or trough between dunes is called a *slack*. A "dune field" or erg is an area covered by extensive dunes.

Dunes occur in some deserts and along some coasts. Some coastal areas have one or more sets of dunes running parallel to the shoreline directly inland from the beach. In most cases, the dunes are important in protecting the land against potential ravages by storm waves from the sea. Although the most widely distributed dunes are those associated with coastal regions, the largest complexes of dunes are found inland in dry regions and associated with ancient lake or sea beds. Dunes can form under the action of water flow (fluvial processes), and on sand or gravel beds of rivers, estuaries and the sea-bed.

Formation

Dunes are made of sand-sized particles, and may consist of quartz, calcium carbonate, snow, gypsum, or other materials. The upwind/upstream/upcurrent side of the dune is called the stoss side; the downflow side is called the lee side. Sand is pushed (creep) or bounces (saltation) up the stoss side, and slides down the lee side. A side of a dune that the sand has slid down is called a slip face (or slipface). The Bagnold formula gives the speed at which particles can be transported.



Sand hitting sand is more likely to stick; sand hitting a more coherent surface is more likely to bounce (saltation). This exacerbating feedback loop helps sand accumulate into dunes.

Aeolian dunes

Aeolian dune shapes

Five basic dune types are recognized: crescentic, linear, star, dome, and parabolic. Dune areas may occur in three forms: simple (isolated dunes of basic type), compound (larger dunes on which smaller dunes of same type form), and complex (combinations of different types).

Barchan or crescentic

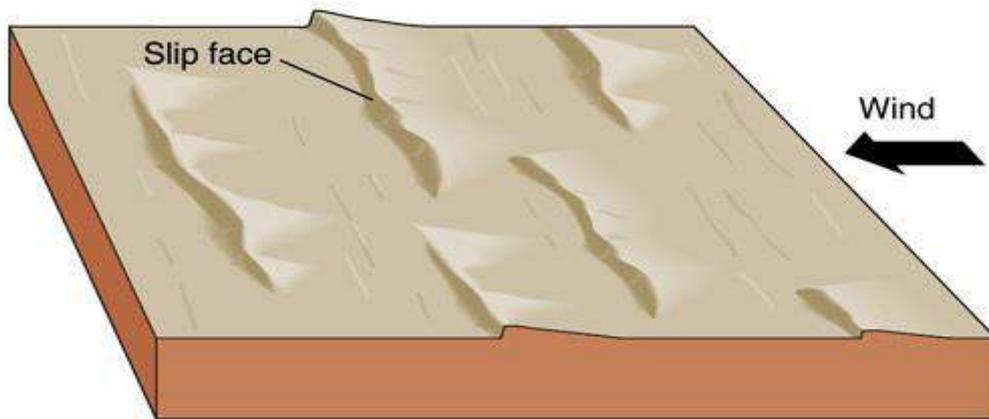
Barchan dunes are crescent-shaped mounds which are generally wider than they are long. The lee-side slipfaces are on the concave sides of the dunes. These dunes form under winds that blow consistently from one direction (unimodal winds). They form separate crescents when the sand supply is comparatively small. When the sand supply is greater, they may merge into barchanoid ridges, and then transverse dunes (see below).



Isolated barchan dunes on the surface of Mars. Dominant wind direction would be from left to right.

Transverse dunes

Abundant barchan dunes may merge into barchanoid ridges, which then grade into linear (or slightly sinuous) transverse dunes, so called because they lie transverse, or across, the wind direction, with the wind blowing perpendicular to the ridge cre.



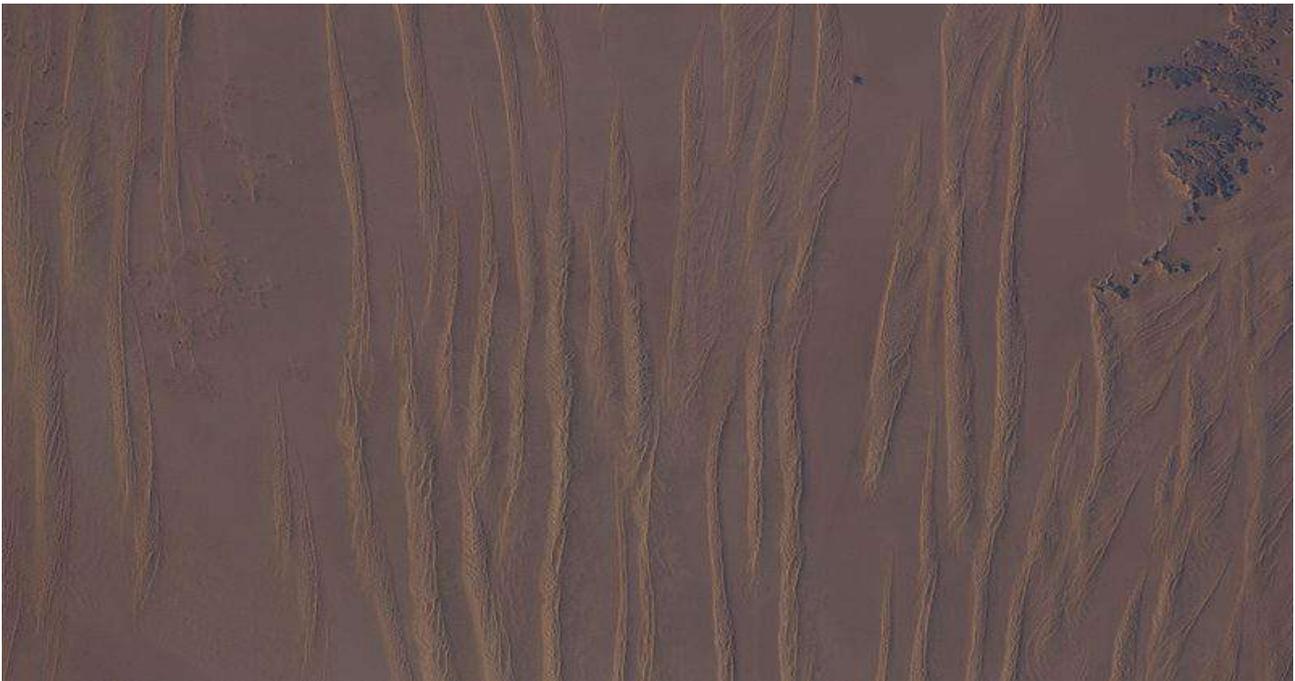
Transverse dunes form with the wind blowing perpendicular to the ridges, and have only one slipface, on the lee side. The stoss side is less steep.

Seif or longitudinal dunes

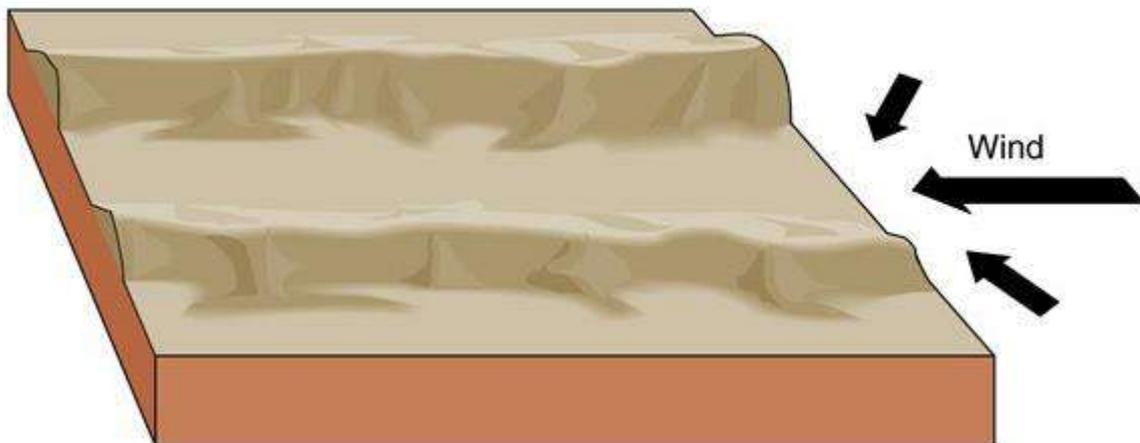
Seif dunes are linear (or slightly sinuous) dunes with two slip faces. The two slip faces make them sharp-crested. They are called *seif* dunes after the Arabic word for "sword". They may be more than 160 kilometres (100 miles) long, and thus easily visible in satellite images (see illustrations).

Seif dunes are associated with bidirectional winds. The long axes and ridges of these dunes extend along the resultant direction of sand movement (hence the name "longitudinal". Some linear dunes merge to form Y-shaped compound dunes.

Formation is debated. Bagnold, in *The Physics of Blown Sand and Desert Dunes*, suggested that some seif dunes form when a barchan dune moves into a bidirectional wind regime, and one arm or wing of the crescent elongates. Others suggest that seif dunes are formed by vortices in a unidirectional wind. In the sheltered troughs between highly developed seif dunes, barchans may be formed, because the wind is constrained to be unidirectional by the dunes.



Large linear seif dunes in the Great Sand Sea in southwest Egypt, seen from the International Space Station. The distance between each dune is 1.5-2.5 km.



The average-direction-longitudinal model of seif dune formation

Seif dunes are common in the Sahara. They range up to 300 m (980 ft) in height and 300 km (190 mi) in length. In the southern third of the Arabian Peninsula, a vast erg, called the Rub' al Khali or Empty Quarter, contains seif dunes that stretch for almost 200 km and reach heights of over 300 m.

Linear loess hills known as pahas are superficially similar. These hills appear to have been formed during the last ice age under permafrost conditions dominated by sparse tundra vegetation.

Star

Radially symmetrical, star dunes are pyramidal sand mounds with slipfaces on three or more arms that radiate from the high center of the mound. They tend to accumulate in areas with multidirectional wind regimes. Star dunes grow upward rather than laterally. They dominate the Grand Erg Oriental of the Sahara. In other deserts, they occur around the margins of the sand seas, particularly near topographic barriers. In the southeast Badain Jaran Desert of China, the star dunes are up to 500 metres tall and may be the tallest dunes on Earth.



An isolated star dune

Dom

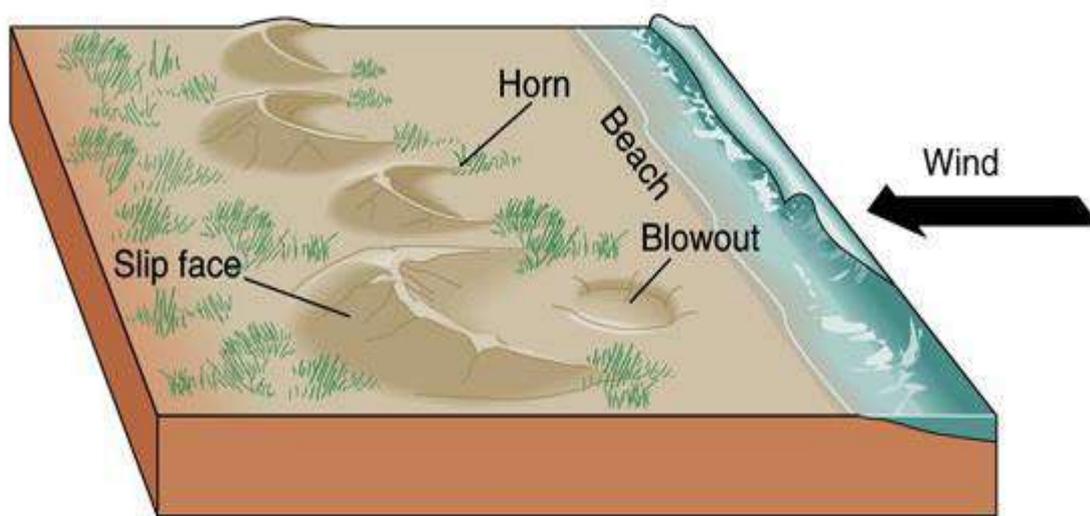
Oval or circular mounds that generally lack a slipface. Dome dunes are rare and occur at the far upwind margins of sand seas.

Lunettes

Fixed crescentic dunes that form on the leeward margins of playas and river valleys in arid and semiarid regions in response to the direction(s) of prevailing winds, are known as lunettes, source-bordering dunes, bourrelets and clay dunes. They may be composed of clay, silt, sand, or gypsum, eroded from the basin floor or shore, transported up the concave side of the dune, and deposited on the convex side. Examples in Australia are up to 6.5 km long, 1 km wide, and up to 50 metres high. They also occur in southern and West Africa, and in parts of the western United States, especially Texas.

Parabolic

U-shaped mounds of sand with convex noses trailed by elongated arms are parabolic dunes. These dunes are formed from blowout dunes where the erosion of vegetated sand leads to a U-shaped depression. The elongated arms are held in place by vegetation; the largest arm known on Earth reaches 12 km. Sometimes these dunes are called U-shaped, blowout, or hairpin dunes, and they are well known in coastal deserts. Unlike crescent shaped dunes, their crests point upwind. The bulk of the sand in the dune migrates forward.



Schematic of coastal parabolic dunes

Reversing dunes

Occurring wherever winds periodically reverse direction, reversing dunes are varieties of any of the above shapes. These dunes typically have major and minor slipfaces oriented in opposite directions. The minor slipfaces are usually temporary, as they appear after a reverse wind and are generally destroyed when the wind next blows in the dominant direction



Reversing dune showing short minor slipface atop the major stoss (upwind) face

Draas

Draas are very large-scale dune bedforms; they may be tens or a few hundreds of metres in height, kilometres wide, and hundreds of kilometres in length. After a draa has reached a certain size, it generally develops superimposed dune forms. They are thought to be more ancient and slowermoving than smaller dunes, and to form by vertical growth of existing dunes. Draas are widespread in sand seas and are well-represented in the geological record.



Dune complexity

All these dune shapes may occur in three forms: simple (isolated dunes of basic type), compound (larger dunes on which smaller dunes of same type form), and complex (combinations of different types).[3] Simple dunes are basic forms with the minimum number of slipfaces that define the geometric type. Compound dunes are large dunes on which smaller dunes of similar type and slipface orientation are superimposed. Complex dunes are combinations of two or more dune types. A crescentic dune with a star dune superimposed on its crest is the most common complex dune. Simple dunes represent a wind regime that has not changed in intensity or direction since the formation of the dune, while compound and complex dunes suggest that the intensity and direction of the wind has changed.

Dune movement

The sand mass of dunes can move either windward or leeward, depending on if the wind is making contact with the dune from below or above its apogee. If wind hits from above, the sand particles move leeward. If sand hits from below, sand particles move windward. The leeward flux of sand is greater than the windward flux. Further, when the wind carrying sand particles when it hits the dune, the dune's sand particles will saltate more than if the wind had hit the dune without carrying sand particles.

Coastal Dunes

Coastal dunes form when wet sand is deposited along the coast and dries out and is blown along the beach. Dunes form where the beach is wide enough to allow for the accumulation of wind-blown sand, and where prevailing **onshore winds** tend to blow sand inland. The three key ingredients for coastal dune formation are a large sand supply, winds to move said sand supply, and a place for the sand supply to accumulate. Obstacles-for example, vegetation, pebbles and so on-tend to slow down the wind and lead to the deposition of sand grains. These small "incipient dunes or

"shadow dunes" tend to grow in the vertical direction if the obstacle slowing the wind can also grow vertically (i.e., vegetation). Coastal dunes expand laterally as a result of lateral growth of coastal plants via seed or rhizome. Models of coastal dunes suggest that their final equilibrium height is related to the distance between the water line and where vegetation can grow. Coastal dunes can be classified by where they develop, or begin to take shape. Dunes are commonly grouped into either the Primary Dune Group or the Secondary Dune Group. Primary dunes gain most of their sand from the beach itself, while secondary dunes gain their sand from the primary dune. Along the Florida Panhandle, most dunes are considered to be foredunes or hummocks. Different locations around the globe have dune formations unique to their given coastal profile.

Coastal sand dunes can provide privacy and/or habitats to support local flora and fauna. Animals such as sand snakes, lizards, and rodents can live in coastal sand dunes, along with insects of all types. Often the vegetation of sand dunes is discussed without acknowledging the importance that coastal dunes have for animals. Further, some animals, such as foxes and feral pigs can use coastal dunes as hunting grounds to find food. Birds are also known to utilize coastal dunes as nesting grounds. All these species find the coastal environment of the sand dune vital to their species survival.

Over the course of time coastal dunes may be impacted by tropical cyclones or other intense storm activity, dependent on their location. Recent work has suggested that coastal dunes tend to evolve toward a high or low morphology depending on the growth rate of dunes relative to storm frequency. During a storm event, dunes play a significant role in minimizing wave energy as it moves onshore. As a result, coastal dunes, especially those in the foredune area affected by a storm surge, will retreat or erode. To counteract the damage from tropical activity on coastal dunes, short term post-storm efforts such as fences can be made by individual agencies through fencing to help with sand accumulation.

How much a dune erodes during any storm event is related to its location on the coastal shoreline and the profile of the beach during a particular season. During the summer, a beach tends to take on more of a convex appearance due to gentler waves, while the same beach in the winter may take on more of a concave appearance. As a result, coastal dunes can erode much more quickly in the winter than in the summer.

As a dune forms, plant succession occurs. The conditions on an *embryo dune* are harsh, with salt spray from the sea carried on strong winds. The dune is well drained and often dry, and composed of calcium carbonate from seashells. Rotting seaweed, brought in by storm waves adds nutrients to allow pioneer species to colonize the dune. These pioneer species are marram grass, sea wort grass and other sea grasses in the United Kingdom. These plants are well adapted to the harsh conditions of the foredune typically having deep roots which reach the water table, root nodules that produce nitrogen compounds, and protected stomata, reducing transpiration. Also, the deep roots bind the sand together, and the dune grows into a foredune as more sand is blown over the grasses. The grasses add nitrogen to the soil, meaning other, less hardy plants can then colonize the dunes. Typically these are heather, heaths and gorses. These too are adapted to the low soil water content and have small, prickly leaves which reduce transpiration. Heather adds humus to the soil and is usually replaced by coniferous trees, which can tolerate low soil pH, caused by the accumulation and decomposition of organic matter with nitrate leaching. Coniferous forests and heathland are common climax communities for sand dune systems.

Ecological succession on coastal dunes

Young dunes are called yellow dunes and dunes which have high humus content are called grey dunes. Leaching occurs on the dunes, washing humus into the slacks, and the slacks may be much more developed than the exposed tops of the dunes. It is usually in the slacks that more rare species are developed and there is a tendency for the dune slacks soil to be waterlogged and where only marsh plants can survive. These plants would include: creeping willow, cotton grass, yellow iris, reeds, and rushes. As for the species, there is a tendency for natterjack toads to breed here.