WIND: A GLOBAL GEOLOGIC PROCESS
Smith and Pun, Chapter 20

WHY WIND BLOWS

Wind is motion in the atmosphere. Movement of gas molecules in the atmosphere occurs for the same reason that motion occurs within the solid Earth – convection.

Denser air sinks to Earth’s surface and displaces the less dense air upward (see Figure 20.2, page 616). Temperature and water vapor are two variables that contribute to density differences in the atmosphere.

Heating causes atmospheric gases to expand so that warm air is less dense than cool air.

Humid air is less dense than dry air at the same temperature because the water molecule has a lower mass than the N and O molecules that compose most of the atmosphere.
WHY WIND BLOWS (2)

Wind speed is determined by the pressure difference between adjacent regions of high and low air pressure.

The greater the difference in air pressure, the faster the wind speed.

Windy storms and hurricanes are associated with areas of extremely low air pressure where warm, moisture-rich air rises upward rapidly. The large difference in air pressure between the storm region (extremely low pressure), and adjacent areas with higher pressure is one cause of high-velocity winds that result in damages.

GLOBAL WIND PATTERNS

To understand global wind patterns, the first observation is that the equatorial region receives more direct solar energy than the poles (see Figure 20.3a, page 618). Therefore,

- Dense, cool air descends at the poles and moves toward the equator where less dense, warm air ascends.

- Air moves from surface high pressure near the poles toward a belt of surface low pressure along the equator.
GLOBAL WIND PATTERNS (2)

Next, we need to consider the effect of moisture transport on convection (see Figure 20.3b, page 618). Warm air rising from the low pressure belt at the equator is also rich in water vapor, because warm temperatures favor evaporation, and warm air holds more water vapor than cold air.

- This initially warm, moist air mass cools as it moves higher into the atmosphere. Cooling occurs in response to the upward decrease in air pressure that results from the decrease in the weight of overlying atmosphere with height.
- The cooling air cannot hold the water vapor that was absorbed when the air was warmer at the surface.

GLOBAL WIND PATTERNS (3)

The simple convection between equator and poles depicted in Figure 20.3a is cut short by sinking of cool, dry air only 30 degrees north and south of the equator (Figure 20.3b).

- The descending air forms high pressure belts at these subtropical latitudes and then flows both northward and southward.
- Descending cold air near the poles forces another convection loop at high latitudes.

The final step in constructing actual global wind patterns is to add in the effect of Earth’s rotation.
GLOBAL WIND PATTERNS (4)

Rotation causes all objects that move over Earth’s surface or through the atmosphere to experience a horizontal drift called the Coriolis effect. The Coriolis effect is named in honor of the 19th century French engineer who mathematically quantified it.

The Coriolis effect shifts moving objects to the right of their initial path in the northern hemisphere and to the left in the southern hemisphere (see Figure 20.3c, page 618).

For example, air moving southward from the northern hemisphere subtropical high pressure zone deflects to the right (toward the west) to produce easterly winds; air moving northward from the high pressure belt deflects to the right to produce westerly winds.

GLOBAL WIND PATTERNS (5)

The Coriolis effect works with convection to produce westerly and easterly winds. What remains unexplained, however, is why wind directions are not constant throughout the year.

1. Solar heating of the surface and atmosphere differs with the seasons. This means that high and low pressure regions and the winds between them shift with the seasons.

2. Land and ocean surfaces heat unevenly. Land surfaces reflect more heat into the atmosphere than oceans during the summer months, which produces low pressure areas of rising, warm air above the land.
GLOBAL WIND PATTERNS (6)

The overall effect is that winter wind patterns (shown in Figures 20.3d and 20.3e, page 618) closely resemble the pattern shown in Figure 20.3c.

Subtropical high pressure forms a fairly continuous belt that circles the globe close to 30 degrees latitude, and this belt separates zones of easterly and westerly winds.

During the summer months, lower air pressure over the continents breaks up the continuous belt of high pressure. Very low summer air pressure over southeastern Africa, southern Asia, and northern Australia draws in moist air from adjacent oceans to cause torrential seasonal rains, called monsoons.

LOCAL WIND PATTERNS

Local surface features also cause local variations from the global wind pattern.

- High mountains block or deflect wind near the surface.
- Small convection cells may form because of differential heating and cooling of the Earth’s surface. These small circulation patterns produce distinctive winds in coastal (see Figure 20.4, page 620) and glacial regions.
WHERE WINDS SHAPE LANDSCAPES

The impact of wind on landscapes is most apparent in places where the following three conditions occur:

1. Strong winds blow frequently.
2. Vegetation is sparse or absent.
3. Small, loose dry particles are abundant on the surface.

See Figure 20.5, page 621.

WHERE WINDS SHAPE LANDSCAPES (2)

The presence of vegetation decreases the effectiveness of wind at shaping landscapes because:

1. Plant roots bind surface particles together so that they cannot be picked up and transported by wind.

2. Plants rise above the land surface and absorb and deflect the force of the wind so that surface particles are sheltered from potential wind erosion.

The sparseness or absence of vegetation in deserts results from a lack of moisture. Deserts are hot or cold arid regions where annual precipitation is less than 25 cm. Widely spaced plants, common in deserts, are not effective in preventing erosion and transport of particles by wind.
WHERE WINDS SHAPE LANDSCAPES (3)

Wind is not as effective as water in picking up surface sediment.

1. Air density is only 1/800\textsuperscript{th} the density of water, so shear stresses exerted on the surface by blowing wind are much lower than those of flowing water.

2. Water also exerts a buoyancy effect on particles that facilitates their movement.

As a result of these limitations, it is uncommon for mineral grains larger than about 0.5 millimeter to be picked up and transported by wind. Wind modification of landscapes, therefore, is only effective where there is abundant, loose, fine-grained sediment on the surface.

WHERE DESERTS OCCUR

Deserts are the largest regions that meet the three requirements for wind to function as an important geologic process (see Figure 20.6, page 623).

Desert regions lack moisture because they are located where:

1. Dry air descends to the surface
2. The air is too cold to hold moisture
3. Mountains block moist air from oceans
4. Moist ocean air moves away from land, or
5. Some combination of these conditions exist (see Figure 20.7, page 624).
WHERE DESERTS OCCUR (2)

**Subtropical Deserts**

Most of the deserts shown on Figure 20.6 are located close to 30 degrees north and south latitude. These include the Sahara Desert, the Arabian Desert, the Kalahari Desert, large areas of Australia, and the deserts straddling the border between the United States and Mexico.

All these deserts coincide with the subtropical high pressure belts within Earth’s atmospheric circulation. Air descending to the surface at these latitudes is dry, having previously lost its moisture to heavy tropical rainfall at the equator.

As the descending air compresses against Earth’s surface, it also warms up, and very high temperatures may result.

WHERE DESERTS OCCUR (3)

**Rain-Shadow Deserts**

Deserts are common on the downwind side of mountain ranges, regardless of latitude. Mountains divert the moist air moving from oceans onto continents upward over the high topography.

- The lifted air expands and cools, which causes condensation of moisture as rain.
- The now denser cool dry air descends the downwind side of the mountains, where it is warmed by compression against the surface and is depleted of moisture.

The rain-shadow effect contributes to desert conditions in the western United States.
WHERE DESERTS OCCUR (4)

Coastal Deserts

Although the atmosphere obtains most of its moisture by evaporation over oceans, some deserts exert in coastal regions. The world record for the longest period without rainfall is 14 years and 4 months at a coastal village in northern Chile.

Other coastal deserts include Baja California, the northwestern Sahara, the Namib Desert in southern Africa, and the northwest coast of Australia.

At these locations, the prevailing wind is from the east on the western edge of continents. Therefore, atmospheric circulation carrier dry continental air offshore, rather than bringing moist oceanic air onshore.

WHERE DESERTS OCCUR (5)

Polar Deserts

Cold deserts above 60 degrees latitude contrast with the scorching hot deserts at other locations. The polar regions of North America, Greenland, Siberia, and Antarctica are as dry as the Sahara and, in some places, rarely experience air temperatures above the freezing point of water.

Cold air cannot hold significant moisture, so these high-latitude, high pressure regions are dominated by the downward flow of cold, dry air.
GETTING PARTICLES IN MOTION

Field observations and wind tunnel experiments show that many particles transported by wind are not picked up directly by the wind; instead they are knocked loose from the surface by the impact of other moving particles.

Grains about 0.1 millimeter across are apparently the easiest for wind to pick up. When these small grains bounce along the surface with the blowing wind, they knock loose larger or more cohesive grains that were motionless. Wind tunnel experiments show that each time a bouncing sand grain hits the surface, it dislodges approximately 10 more grains.

See Figure 20.8, page 626.

TRANSPORTING PARTICLES

Once dislodged from the surface, grains move by rolling or bouncing along the ground or are completely suspended in the moving air (see Figure 20.9, page 626).

Field observations and wind tunnel experiments show that small sand grains between 0.1 and 0.3 mm across typically bounce along the surface. Larger grains tend to roll along the ground.

Particles less than 0.1 mm across become suspended in the wind. Dust is the term commonly applied to these suspended particles. Some dust particles settle to the surface when the wind stops blowing; however, grains less than 0.02 mm across are so small that they remain suspended in the atmosphere and may travel thousands of km (see Figure 20.10, page 627).
TRANSPORTING PARTICLES (2)

Movement of sand dunes occurs because most dunes have unequal slopes. The downwind side of the dune is steeper than the upwind side.

- Wind erodes sand on the upwind side that faces into the current. The wind carries a sand grain to the top of the dune, where it then rolls, bounces, or settles onto the downwind side that is sheltered from the wind.

- The dune slowly migrates in the direction of the prevailing wind as erosion occurs on the upwind side and deposition on the downwind side (see Figure 20.11, page 628).

LANDSCAPES ERODED BY WIND

Wind erodes landscapes by two different processes:

1. **Deflation** is the process through which landscape elevations are lowered as wind removes the finer particles.

2. Abrasion by wind blown particles erodes exposed rock and regolith surfaces. Abrasion has the effect of sandblasting and slowly wears away sediment grains that are too large for wind to pick up.
LANDSCAPES ERODED BY WIND (2)

Deflation commonly scours out elliptical or circular areas of easily eroded sediment to leave distinctive depressions called pans.

A low dune is typically present on the downwind side of the pan, showing that most of the deflated sediment travels only a short distance prior to deposition.

In regions with fluctuation water tables, pans form during dry periods and then partially fill with infiltrated ground water when the water table rises to the bottom of the pan. Evaporation of water deposits a crust of evaporite minerals to produce a playa on the floor of the pan (see Figure 20.12, page 629).

LANDSCAPES ERODED BY WIND (3)

Ventifacts are loose rocks that show evidence of abrasion by wind blown sand (see Figure 20.12, page 629). The term ventifact is derived from Latin roots and means “made by the wind.”

Persistent sandblasting abrades smooth planar surfaces in rocks that are shaped like polished facets on a gemstone.

The multiple abraded facets result from varying wind directions and shifting of the rock over time.
LANDSCAPES ERODED BY WIND (4)

Deflation and abrasion combine to produce a distinctive landform called a **yardang**, a wind parallel ridge of soft rock or slightly consolidated sediment that remains after surrounding material is eroded. Although the term originated in Turkey, yardangs are recognized on all continents.

- Most yardangs are less than 5 m high and generally no more than 10 m long. They are also very steep sided.
- It is common for the upwind end of the yardang to overhang a notch, because erosion is more intense close to the surface where blowing sand grains contact the outcrop most often.

SAND DUNES

Wind blown sand forms distinctive landforms in deserts and along coastlines.

- In some instances, the sand simply accumulates in low sheets or forms piles at the base of shrubs that block the wind and cause deposition (see Figure 20.14a, page 630).
- Dunes in coastal regions are distinctive because of their height above adjacent beaches, but they rarely cover large areas (see Figure 20.14b, page 630).

Dunes actually cover less than 20 percent of the arid zone surface of Earth, and only 2 percent of desert landscapes in the United States.
SAND DUNES (2)

There are actually five common types of dunes (see Figure 20.15, page 631).

Parabolic dunes form where wind erosion attacks a barren area in a mostly vegetated area, often near a beach. A depression forms where erosion is most intense and the sand is trapped by vegetation to accumulate as a dune.

The U-shape resembles the graph of a parabola with the depression in the center and the two ends of the parabola pointing upwind.

SAND DUNES (3)

Barchan dunes are crescent shaped dunes that form on desert surfaces where gravel or rock are more abundant than sand. Barchan dunes resemble parabolic dunes except that the ends of the crescent barchans point downward (see Figure 20.15, page 631).

Transverse dunes form where sand supply is abundant and the dunes cover large areas. The term “transverse” emphasizes that the curvy dune crests are mostly transverse (perpendicular to the prevailing direction of wind (see Figure 20.15, page 631).
SAND DUNES (4)

Linear dunes are long sand ridges oriented parallel to the prevailing wind direction. Linear dunes commonly form where sand supply is more limited than where transverse dunes form and where wind direction is more variable than regions characterized by barchans (see Figure 20.15, page 631).

Star dunes are radiating sand ridges resulting from highly variable wind directions crossing large areas of readily eroded sand (see Figure 20.15, page 631).

The shapes of sand dunes are ultimately determined by the availability of sand and uniformity of wind direction (see Figure 20.16, page 632).

LOESS DEPOSITS

Geologists use a German term, loess, to describe deposition of wind borne sediment that is mostly silt size on land.

Wind borne silt actually covers nearly as much of the Earth’s surface as is covered by sand dunes (see Figure 20.17, page 633).
DESERT PAVEMENTS

Closely spaced pieces of gravel cover barren and rocky desert floors to form a smooth surface called desert pavement (see Figure 20.18, page 634). Characteristics of desert pavements include:

1. The pavement is usually one to two stones thick.
2. The pavement overlies silt.

Desert pavements are important in reducing erosion because pavement particles are too large to be eroded by wind and form a surface armor.

DESERT PAVEMENT (2)

There are two hypotheses for the formation of desert pavement.

The deflation hypothesis states that wind deflates sand and dust particles within poorly sorted surface deposits that include gravel (see Figure 20.19a, page 635).

Over time, the abundance of gravel fragments on the surface increases as finer particles are blown away.

Eventually the surface is completely covered with coarse particles that the wind is unable to move.
DESER PAVEMENT (3)

The deflation hypothesis is consistent with the occurrence of pavements in deserts throughout the world where wind is clearly an important geologic process. This hypothesis, however, does not explain two other features:

1. Silty layers, in some instances tens of cm thick, immediately underlie the pavement armor but contain few if any gravel fragments. Deflation of fine-grained sediment would not leave behind a layer of gravel.

2. Some data reveal that all of the pavement clasts have been at the surface for the same period of time, whereas deflation requires exposure of clasts over an extended time period.

DESSERT PAVEMENT (4)

An alternative hypothesis for the formation of desert pavement is more complicated, but more consistent with the observed data (see Figure 20.19b, page 635).

1. Clasts projecting above the surface of an initially coarse deposit trap wind blown dust particles. The dust sifts into cracks between surface clasts, possibly aided by infiltrating rainwater.

2. The dust includes silt- and clay-size particles that shrink and swell during drying and wetting. The shrinking and swelling action, along with mineral dissolution and precipitation, shift the surface clasts around and open cracks in the accumulating fine-grained layer.
DESERT PAVEMENT (5)

3. Slow gradual accumulation of dust progressively lifts the surface gravel fragments higher and higher above their original starting point.

This hypothesis also reveals that development of the landscape was due to wind deposition rather than wind erosion.