# In the Name of God

# Unit 6: Desert geomorphology

## Introduction

All across the planet Earth, natural processes mold and shape the planet into new manifestations each day. Knowledge of these processes, which act over time scales ranging from several days to millions of years, are an essential part of understanding the Earth and its history. One of the largest processes that has persisted across the millennia is that of **desertification**. In general people consider a **desert** to be a place devoid of life and vegetation with no obvious purpose except heat, death, and despair. Little do they know that deserts are not only the home to hundreds of plant and animal species, they also are a direct result of climate and regional changes that are diagnostic of **arid lands**.

In order to understand the past, present, and future of deserts and desertification one must first understand the processes by which features such as **dunes, ripples, and interdune structures** are created. Secondly, the **stratigraphic record** can be examined to find an example of what happens when a desert undergoes **burial** and **lithification**. Next a modern example, namely **the Sahara Desert**, will be discussed so that interpretations can be made from modern climate conditions. Finally the impact of climate and land overuse can be discussed to predict where and why future deserts will occur.

## Desert Processes and Features

There are several factors that are necessary for the formation of a desert, of which climate and **sand source** are the most important for the purpose of this paper. In regards to sand sources two types of deserts can be formed. **Sandrich deserts** have a plentiful sand source whereas **sand-poor deserts** have no readily available sand source. This paper will deal mainly with sand-rich deserts. The climate must be arid, with little to no rainfall per year, and have either high temperature or very cold, windy air to aid in moisture removal. Deserts are generally prevalent in the **moisture-starved plains** on the **leeward side** of a **mountain chain**. In this case, winds carrying moisture deposit rain and snow in the mountain chain due to temperature and pressure variations, leaving little to no moisture for the leeward side of the mountain. This area tends to have heavy wind activity with the mountains providing a **steady sediment supply**. In contrast, areas can still be subject to desertification but have no steady sediment supply. In these cases, the land simply becomes moisture-parched and **barren** of plant and animal species that require large amounts of water for survival.

## Abrasion Processes

Before desert and dune features can be discussed, it is important to provide relevant information on the **abrasional processes** which help to supply sediment to the desert. The processes by which wind erodes can be defined as **deflational**, where **unconsolidated sediment** is entrained, and as abrasional, where cohesive material is worn down. These concepts can be combined to show exactly how **consolidated rock** can be worn down by the wind.

The actual process of abrasion is quite simple. **Airborne particles** are carried or saltate until impact with another object occurs. Several variables must be considered when discussing these impacts. Factors such as **wind velocity**, **grain size**, target (a **cohesive rock**) durability (includes density, **mineral hardness**, **induration**, existing **fractures**) and airborne grain size and hardness will affect how much erosion can occur. For example, slow wind velocities or hard target rocks will result in low erosion rates, whereas high wind velocities and a poorly indurated target rock will result in high erosion rates. In all actuality the **wind speed** would have to increase up to 200 mph to cause suspension of most grains.

In addition to wind velocity and grain size, several other factors must be considered as affecting abrasion rates. First of all, a constant grain source must be available for the abrasion to persist. Second, these grains must not be in **high concentration**. This would cause loss of **kinetic energy** by grain to **grain collision** which would lessen the force of the impact on the target rock. Finally, the surface being abraded must be **inclined** less than 90 degrees for erosion inducing impact. This is important because the grains can cause more **damage** to existing fractures and chips by impacting at a low angle than at a higher one.

## Dunes

The most distinctive of all desert features are dunes. A dune, as defined by Cooke et al. (1990), is a **subaerial body of sand** 30 cm to 400 m tall and 1 m to 1 km wide that is shaped by wind conditions and placement of sand particles. Despite the huge range stated in the definition sand dunes at the lower margin of the defined size would not persist in a variable speed wind environment and would probably disperse, grow, or accrete to another dune.

The two main types of dunes are **stationary**, which do not move, and **migratory**, which change location as the wind **blows**. Stationary dunes are always characterized by having an anchoring landform such as **rock outcrops** or plant life. Dunes caught on plants most likely will occur in **marginal desert environments** such as **sabkas** and at the base of a **leeward** mountain slope. Migratory dunes can also be subdivided into several categories; the most common are **transverse dunes and linear dunes**. Transverse dunes are dunes with short lengths, long widths, and variable heights. They generally have a **gently sloping windward side** and a **steeply sloping leeward side**. This type of dune will be the main focus of the discussion of dune dynamics in this paper. Linear dunes grow by extension down-wind and are oriented near-parallel to oblique to the wind. These dunes are steeper than transverse dunes and usually **asymmetrical**.

The origin of a dune would seem to be an easy question that should result in an easy answer. Where does a dune come from? Obviously from accumulated **blowing sand**. Despite this, there is a bit more explaining that has to be done to fully answer this question. Cooke et al (1993) explains the dune-forming process as occurring in one of two methods. The first method is by **sand accumulating** in different surface levels. **Small pits**, **hollows**, and even **small bumps** can cause accumulation by altering the velocity of the wind. Wind speed will drop when entering a hollow or climbing a slight rise due to **resistance** and **friction**. This decrease in speed causes grains, which have been in transport via **suspension** and **saltation**, to drop out and fill or cover the area. Once these areas are filled or covered, the process will continue because the sand moves with shifts in wind velocity. Eventually slight sand **ripples** will grow to dune size, hence forming dunes.

Several variables must be considered as affecting the dune formation process described above. First of all this model requires a relatively consistent wind direction. Drastic shifts in wind direction would cause excessive erosion and alteration of the shape of the dune. Another similar variable for consideration is wind velocity, which could also cause an increase in erosion. When combined, a drastic change in wind velocity and direction could cause various changes in **dune dimensions**.

The second process by which dunes are shaped is quite simple. First a stationary dune must develop. Then, when wind speeds or **sliding of grains** on the dune increase to more than the **anchor** can hold, the dune will slowly migrate off its anchor and become a migratory dune. Stationary dunes with strong anchors will simply decrease in size or **disaggregate** completely when wind velocities increase enough to disperse **individual sand grains**.

The next aspect of dune activity that must be examined is the process by which transverse dunes migrate and replicate. As wind travels up the windward side of a dune, particles of sand are taken into saltation as well as pushed off of the peak of the dune. These pushed particles can create **avalanches of grains** that slowly pile up on the leeward side of the dune. Other particles can continue to saltate to the next dune where they may either stop or move on, depending on the wind velocity. Not all saltating particles stop at each dune. Particle size, being variable, will dictate a grain's movement from dune to dune. Heavier grains will saltate smaller distances or remain as bedload, while smaller grains will achieve longer leaps. This is an ongoing cycle in which grains migrate from dune to dune as long as wind velocities remain strong enough. The cycle is continuous so that dunes stay at or grow to an **equilibrium** size depending on the wind speed. The amount of grains that **blow off** a given dune is about equal to the number accreted onto the dune when it is in equilibrium. In contrast, this equilibrium size will change when wind velocity or direction change therefore causing the dune to alter size and shape to reach a new equilibrium.

**Dune replication** occurs in much the same fashion as dune migration. As wind speeds change variably, the sizes of dunes will also change. Shifts in wind direction can cause the dunes to form a distorted shape (much like 3-D ripples), which can force a portion of the dune to break off and migrate on its own. This dune, if given enough space, will grow on its own and undergo the same accumulation/erosion process that affects the other dunes.

## Ripples and lnterdune Features

Ripples are a common desert feature, and tend to occur on the windward side of transverse dunes. Ripples, like dunes, vary in size with wind speed and grain size and form from the same processes as dunes, except at a smaller scale. Several models of ripple formation have been introduced of which one is generally accepted today. This model, the "**ballistic model**", was first introduced by Bagnold in 1941. This model suggests that ripples will form when grains are deposited one saltation length downwind from a depression or obstruction that they hit on the dune surface. This process continues until a ripple is formed.

Some potential problems exist with this model. For example, if the saltated grains are not of the same size, or if the wind speed does not remain constant, then the grains could land in a near-random pattern. Since ripples are relatively small dune features and they form over a short period of time, however, these problems appear to be overcome during ripple formation by short term **consistency** of wind speed and sediment size supplied. As it was explained earlier, grain movement depends on the size of the grain and the speed of the wind. Ripples usually contain a relatively consistent grain size so at a constant wind speed these grains would saltate at a reasonably equal distance, not in a **random pattern** as stated by the ballistic model. This process, the ballistic model, was later revised to account for these variables, and become an **acceptable hypothesis**. Since this process mimics that of dune formation it is obvious that ripples are subject to the same migration and equilibrium patterns that dunes are.

Other structures than can be seen inside of dunes (in **cross-section**) include **truncation** surfaces and **slipface strata**. Truncation surfaces are surfaces to which a dune was at one time was eroded, either by a sandstorm or by large dune movement. These surfaces are commonly referred to as **bounding surfaces and planes**. One type is known as a **supertruncation surface**, and can be recognized as a complete pause in dune formation as the result of an erosional event. In this case a **paleosol** usually develops on this surface. Other types of truncation surfaces are classified as being first, second, or third order. First order surfaces are formed by the passage of large dunes, tend to be low angle, and are laterally extensive. Second order surfaces have the same characteristics as first order surfaces, except they gently dip and are caused by the migration of medium dunes. Third order surfaces are formed by daily and seasonal erosion as well as wind direction change. Slipface strata, also known as cross-stratification or **foreset strata**, fall into two categories. The first, **sandflow strata**, are formed when a stream of sand falls from atop a dune crest, forming a long **lenticular sandflow** on the leeward side of a dune. The second, **slump strata**, are formed when **coherent bodies** of sand slide down a slipface forming a larger sheet of sand on the leeward side of a dune.

## Lithification of Desert Deposits

In order for a **sequence of desert deposits** to become **lithified** several things must happen. First of all, there must be a continuous source of cement or multiple discontinuous stages of **cementation**, which will intermingle with the sand grains, forming a cohesive bond upon burial. Second of all, the desert deposits must remain long enough (i.e., the deposits are not reworked) to be buried and lithified. Most **eolian sandstones** have a **carbonate cement**, which is indicative of a nearby **calcareous environment**. Consequently, the existence of an ocean, inland sea, or extensive lake would provide enough carbonate from its beaches and carbonate enriched groundwater. This carbonate sand can interfinger with the desert sand and cause lithification of the deposit under certain circumstances. If the desert is by a body of water, offshore storms can drench the sands, slowly dissolving the carbonate and instigating a slow cementation process.

If the desert is not located near a body of water, or if the prevailing winds blow in the wrong direction, cementation can occur another way. Subsequent burial of the dunes due to a constant **sediment influx** will eventually bury sand layers to the level of the water table. Any carbonate present in the deposit will be dissolved, then shifts in the level of the water table over time will precipitate the carbonate to form a grain to grain cement. Furthermore, most water will eventually be removed by pressure once the sand has been buried deep enough allowing any carbonate in the water to precipitate onto the grains. This can also occur with other types of cement. Carbonate is used as an example because it is most important towards deposits described in this paper. One thing that must be realized is that this is a gradual process which takes an amount of time unfathomable by the average human.

## Top 10 Scientific Journals related to Water Sciences

1- ***Journal of Arid Environment***
2- ***Hydrology and Earth System Sciences***
3- ***Earth Surface Processes and Landforms***
4- ***Catena***
5- ***Geoderma***
6- ***Soil Science***
7- ***Land Degradation and Rehabilitation***
8- ***Australian Journal of Soil Research***
9- ***Journal of Soil Science***
10- ***Geomorphology***