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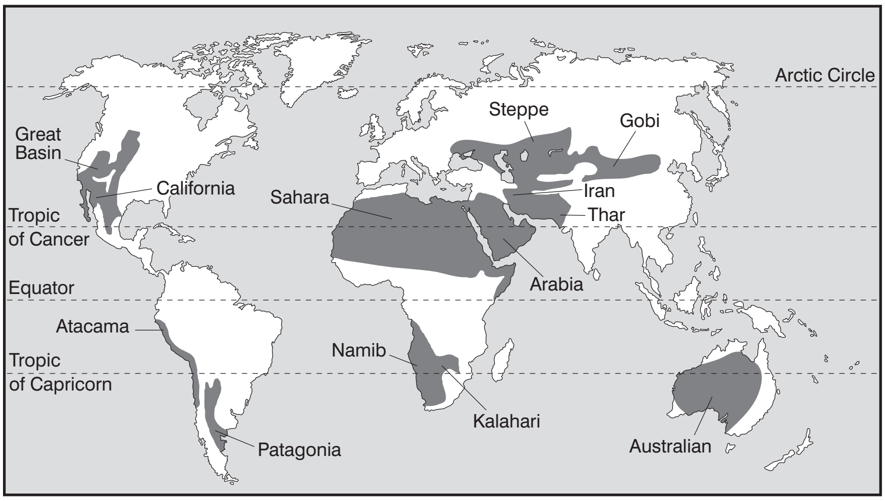
Mike Wynn

Arid and Semi-arid Landscapes and Landforms

The world map (Figure 1) illustrates the location and extent of arid and semi-arid areas. Latitudinally they mostly extend between 10 and 33 degrees. There is a wide range of desert types and landscapes: the coastal deserts, eg Atacama, continental deserts, eg Sahara, high altitude deserts, eg Gobi. Within deserts there is a huge variety of landscapes. The Sahara is the largest desert in the world and includes the volcanic areas of the Hoggar (2918m) and Tibetsi Massifs (3265m), the Qattara Depression 320 by 160 km in extent and 134m below SL, the hammadas (stony flat plains), reg (gravel/pebble plains) as well as the great sand seas (erg). Mountains occupy 43% of the Sahara, sand seas only 28%. Altogether about one-third of the world's land surface is arid (extremely arid 4%, arid 15%, semi-arid 14.6% - Goudie).

Figure 1: Arid and semi-arid areas of the world

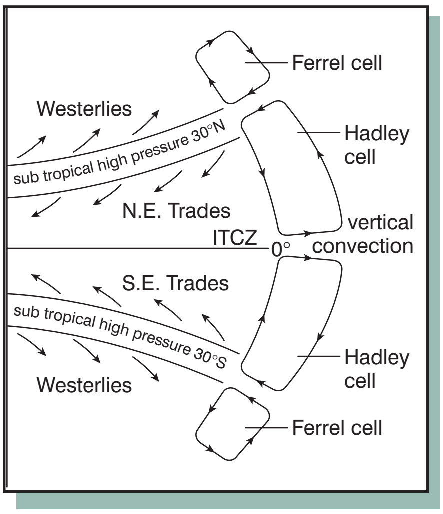


The hot desert climate

Figure 2 indicates the Hadley and Ferrel cells produce sinking air at 30 degrees. This sinking stable air generates the sub tropical high pressure (HP) with a very low relative humidity (RH), the air diverging near the earth's surface to produce the Trade Winds and Westerlies. These circumstances do not produce precipitation, hence the general aridity of these areas.

Continentality is a factor affecting large deserts (In Salah Jan 13°C, July 36°C, 15mm). The Atacama and Namib are arid due to the cold offshore current (Lima 45mm). Other deserts are in rain shadow, eg Patagonia and on a larger scale the onshore SE Trade winds of eastern Australia dump precipitation along the east coast and Great Dividing Range then descend and warm up into the interior of Australia (Alice Springs 249mm).

Figure 2: Atmospheric circulation related to arid and semi-arid regions



Temperatures can reach 50 to 55°C with high rates of insolation in the almost cloudless sky (RH 5%), but at night with no cloud cover intense radiation leads to a rapid drop in temperature, giving a large diurnal range, both in summer and winter and a RH of 60%, enough to precipitate dew or frost. This moisture can be important for the weathering process. Occasionally desert convection currents are strong enough to rise through the descending HP air, they then form cumulonimbus clouds that can generate local heavy downpours and maybe cause a flash flood.

The generally accepted definition of deserts is that these areas have less than 250mm of precipitation and semi deserts less then 500mm, but this ignores the high temperatures and high rates of evaporation. The water balance of a desert is dominated by evapotranspiration. Thornthwaite based his general aridity index on potential evapotranspiration, ie evapotranspiration if unlimited water available.

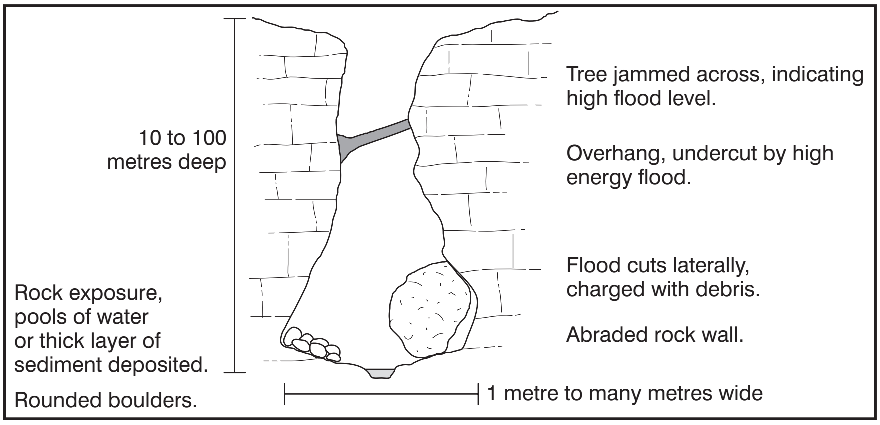
Water in deserts

In desert mountains there are wadis, dry river beds that are only used by water following a local desert storm (Figure 3). Many present-day wadi systems are too large for today's fluvial processes and suggest that they may have been eroded in a wetter period of time.

Many rain events do not cause any runoff, but for the more intensive events the rock surfaces can shed rainwater rapidly.The obvious lack of vegetation and humus mean there is no interception and nothing to retard surface runoff. The desert surface is hard, the sand grains being welded by night time moisture. Raindrops redistribute the sand grains so surface pores become clogged leaving an impermeable surface. There are very few animal burrows or vegetation roots so that low angled slopes (2 degrees) can produce runoff over the whole surface – sheetflow – possibly creating rills and gullies on the steeper slopes.

Following an episodic but intense storm, runoff rapidly gathers into the wadi channel (Figure 3), producing a flash flood full of rock debris and sediment from the wadi floor. Trapped air bubbles up, making the water foam. Friction of water with the wadi floor and its load produces a wave of water resembling a thin mudflow. Erosion can be very significant and much more sediment

Figure 3: Cross-section of wadi



is produced in tons per square km then in temperate or tropical regions, especially in the wetter semi-arid systems. The resulting depositional features are also quite extensive.

These wadis with their ephemeral (intermittent) streams are part of a continuum of features (Figure 5). Where the wadi emerges from the hills on to the desert plain the flow of water and sediment spread out in a series of subdividing (anastomosing) channels. The hydraulic radius decreases so velocity is severely checked and the load is deposited in the form of an alluvial fan, with the finest material travelling furthest. As the alluvial fans grow sideways and forwards, they coalesce.

The water spreads out into an inland depression called a playa lake which is also ephemeral. The water mostly evaporates (groundwater recharge is negligible) leaving behind layers of silt, clay and salt which harden into duricrusts. Evaporite deposits of salt include sodium chloride and salts of nitrate, sulphates and carbonates. The most famous example is the Great Salt Lake in Utah and the Atacama nitrate deposits which are of economic significance. The Nevada desert is formed from enclosed basins surrounded by mountain blocks as a result of faulting. Drainage is intermittent, centripetal (flows to a central point) to the basin and a playa lake, a basin of inland drainage (endoreic drainage) is formed.

Weathering

The variability of the temperature and precipitation conditions all affect the weathering that takes place. Even more effective are the structural and lithological variations which range from the hard shield lands of Australia and India, to the younger faulted block landscape of SW USA and the soft sandstone of Wadi Rum, Jordan.

The diurnal range of air temperature can be large, but that of the surface rocks is much greater. Sparks suggests that thermal expansion and contraction of some homogenous rocks can lead to shattering. When combined with even a small amount of moisture thermal expansion and contraction stresses cause the rock to peel off in layers. This process is called exfoliation (onion skin weathering), once described as a mechanical process but now known to need water.

Salt crystals can form in rocks; sodium chloride and/or sodium carbonate dust can blow about in deserts, settle in the rocks and crystallise, which creates high pressures and splits the rock. Salt crystals also result in the creation of alveoles and tafoni, honeycombed rock surfaces (Figure 6).

Chemical processes and continual temperature changes together cause the decomposition and disintigration of rocks, but only at a very slow rate. The weathered detritus forms the regolith. Chemical weathering leads to differential erosion of softer bands within a rock, creating a mushroom rock. The shade created leads to increased moisture and subsequently chemical weathering, the weathered material being blown away by the wind. In spite of the aridity lichen grows on and in the rock and assists rock weathering as it dissolves the cement between the rock minerals. Rocks on the desert floor are shiny brown-red-black in colour; a varnish of iron and manganese oxides and silica from within the rock, indicating the chemical processes at work. Again, this is likely to be a fossil process as hieroglyphs and rudimentary Neolithic carvings in this varnish on rock walls look as fresh as the day they were carved, notably those in Wadi Rum, Jordan.

The impact of the wind

The wind is an agent of erosion, transportation and deposition in desert geomorphology, picking up sand particles and blasting them at exposed rocks. Sand storms may seem spectacular, but most grains are only just above the surface so the extent of wind erosion is going to be limited in vertical extent. On the desert floor individual pebbles are polished by moving sand and are called ventifacts On a larger scale, yardangs form as the wind erodes softer rock layers, along the strike, leaving outcrops of harder rock stretching for kilometres. Zeugen also develop in this way as unusually shaped rocks (Figure 7).

Depressions, such as Qattara, are found where regolith material is blown away. In such a depression there may be more moisture and chemical weathering leading to further deflation and hollowing. Elsewhere the wind can remove all the sand and leave desert pavement (continuous rock) and boulders. The hammada and reg are also formed in this way.

Ergs (Arabic: region of shifting sand) occupy up to a quarter of the Sahara desert and remain relatively fixed. Where does all the sand come from? Opinion now suggests the Saharan sand has been concentrated in lowland basins by moving water during pluvial periods and today wind is only reworking the sand into ripples, dunes and draas (N. African: large sand hill). By their nature sand dunes are features of deposition caused by a decrease in wind speed in the lee of solid rock or round sparse vegetation. There is now a large classification of sand dunes based on their morphology and from this may come an increased

Figure 4: Hydrograph for an arid area

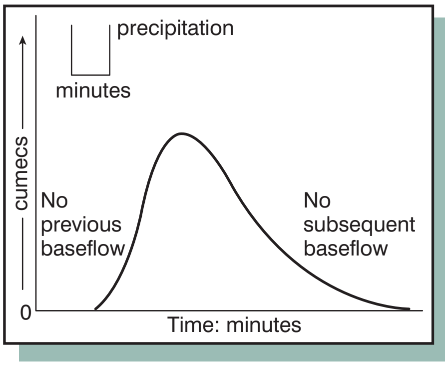
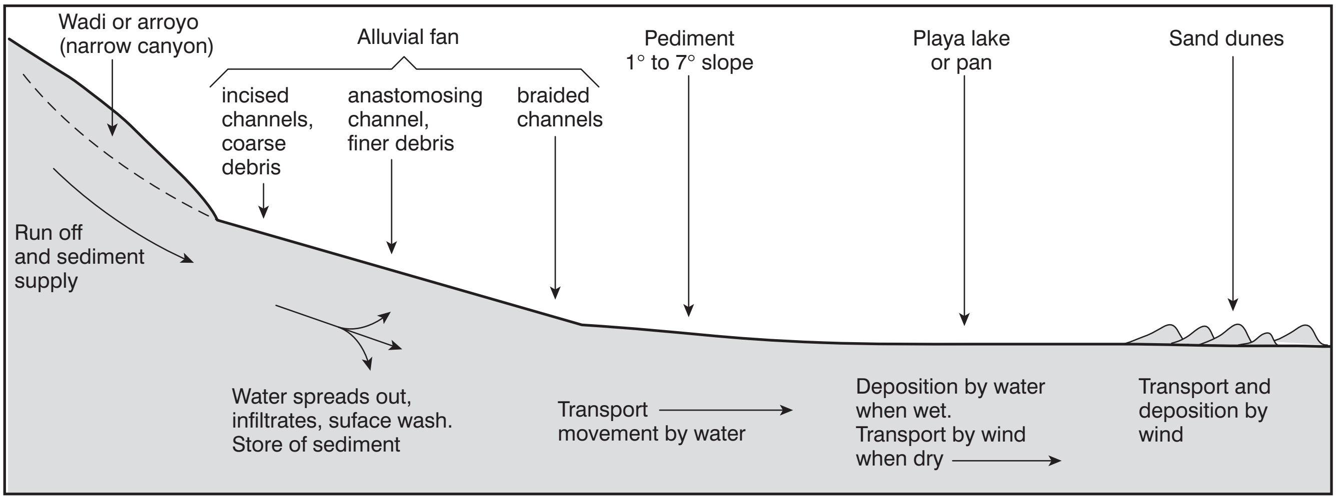


Figure 5: Sequence of some geomorphological features and processes in arid and semi-arid areas



understanding of dune formation. Satellite imagery confirms the importance of wind in dune formation; the huge variety of dunes reflecting the localised as well as the prevailing wind systems (grain size and dune type are not related – Summerfield).

Summerfield classifies dunes into two main groups: free dunes and impeded dunes. Free dunes are formed by unidirectional winds producing transverse ridges, barchanoid ridges or individual barchans (Figure 8). Converging winds produce linear (seif) or longitudinal dunes. Opposing winds produce reversing dunes. Wind sfrom a variety of directions throughout the year produce star shaped dunes. Impeded dunes are related to some local vegetation or physical barrier and have an immense variety. Barchans may be well documented but they are not common. They are formed when the wind blows from one direction. Wind blows sand up the windward slope and over the top keeping the lee slope steep until it slumps. The edges of the dune advance inversely proportional to the height of the slip face, so the horns of the barchan extend, only stopping when they are sheltered by the majority of the dune. They can move up to 50 metres per annum. Draas are found in the southern Sahara and Namib Desert and take a long time to form simply because of the volume of sand, they may be relict features from former geological times.

Thomas indicates that migratory dunes are found on the edges of sand fields. Sand accumulating dunes such as star dunes occur in the centre of dune fields, but different dune types may occur together as they have formed at different times, some can be active, others dormant and some relict.

Figure 6: Honeycombed rock surfaces, the result of salt crystallisation on a rock face, Wadi Rum, Jordan

Figure 7: Solitaire Rock, Wadi Rum, Jordan. An example of a zeugen with a rock platform in the foreground

Slope formation in deserts

L.C. King's 1948 hypothesis of parallel slope retreat, formulated in the semi-arid landscapes of South Africa suggests weathering has caused parallel retreat of the scarp slope through time, allowing the pediment to extend (similar to a wave cut plarform on the coast). Debris from weathering of the scarp forms the constant slope that can be removed by flash floods to cover the pediplain. Sheetflood on the pediplain removes debris but causes no further erosion. The abrupt break of slope between the mountain front and pediment (piedmont junction) represents a break in the processes. Pediments are found in other climatic situations, especially the savanna, but are they characteristic of these areas or a result of past climatic conditions?

As the mountain front is eroded the pediment is left, creating the desert floor, with some isolated blocks of rock left, detached from the mountains (Figure 9). In the SW USA (Monument Valley, Utah) they are termed mesas, flat topped remnants that weather into pinnacles called buttes. In Africa these residual masses are referred to as inselbergs, bornhardts (German: island mountain;domed inselbergs) and koppies which are reduced as backwearing by pediplanation proceeds. Other famous examples are Ayres Rock and the Sugar Loaves of Rio de Janeiro.

Linton, in the UK, researched the formation of granitic tors suggesting subsurface chemical weathering leaving a core of resistant upstanding rock once they are exposed (see *Geographical Review* Vol 16, Nos. 4 & 5 and **Geofile** Jan 2003 No. 436). It is suggested that residual desert masses could be the result of similar processes in a wetter climate especially for the more rounded bornhardts and koppies and subsequently parallel retreat has taken over, especially for inselbergs and mesas. Again, this reminds us of climatic change, features observed today cannot automatically be assigned to the current morphoclimatic conditions.

Figure 8: Dune types – simplified

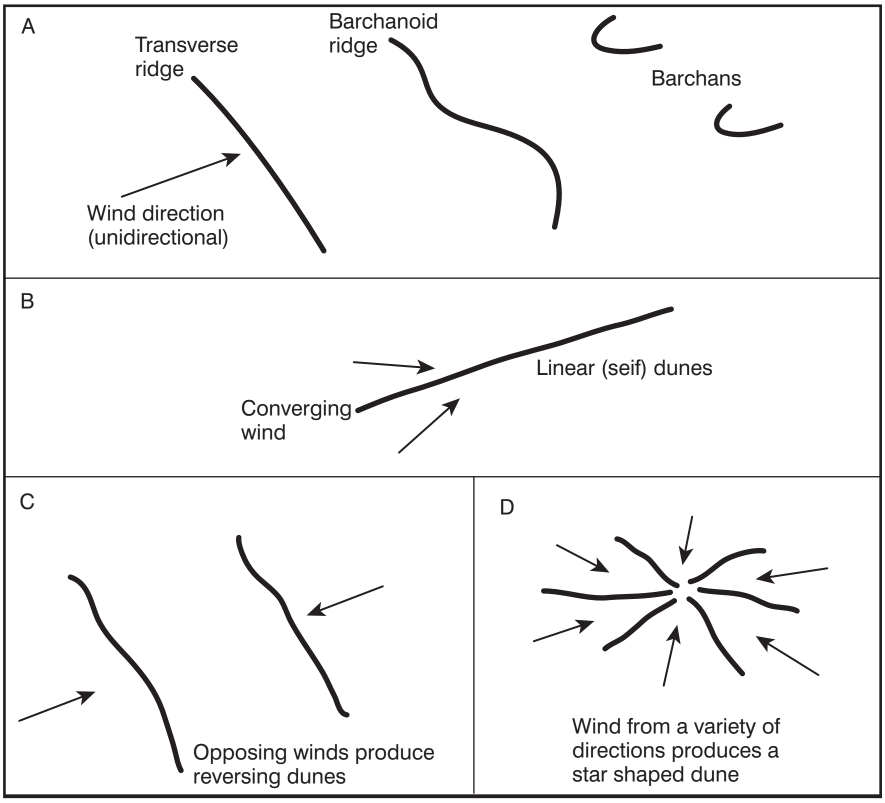
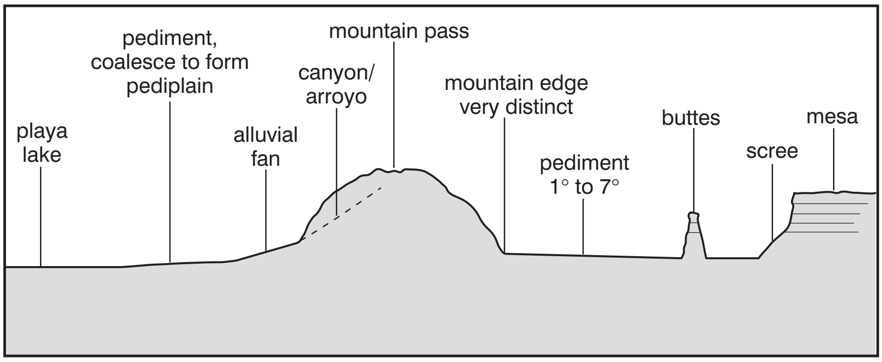


Figure 9: Slope elements involved in parallel retreat



Conclusion

Deserts have both climatic and geomorphological variability. The debate on the relative balance between aeolian and fluvial processes has moved on. Processes operating in deserts are not unique, but latitudinal/spatial changes in climate and vegetation give rise to a distinct geomorphology. Palaeoclimatic conditions indicate a wetter past in deserts and have played a significant part in the formation of landscapes associated with deserts. Today's landforms are often relict features, being slowly modified by today's processes.

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Focus Questions

1. Suggest why it is not possible to equate desert climates with characteristic morphological features.

2. How far are the landforms of arid and semi-arid regions the result of:
- the present climatic regime
- the structure and lithology
- the past climates of these areas?