Desert Processes and Landscape Development

I. INTRODUCTION

A. Landscape evolution in arid and semi-arid regions of the earth can take on a distinctive characteristic of their own. These areas are obviously marked by low annual precipitation, distinctive floral/faunal habitation, and characteristic ephemeral (seasonal) erosion/deposition processes, which include both water and wind as principal driving agents. This section will provide a notable contrast to the more humid fluvial/glacial environments.

B. Definition/Characteristics of Deserts

1. Dry Climate: Rate Evaporation > Rate of Precipitation

a. Arid climate: <10 to 15 inches/year (Desert Regime)

b. Semi-arid: 10-25 inches/year (Steppe Regime)

c. Nature of Rainfall/precipitation- overall year round precipitation is low in desert areas, but is intense in instantaneous accumulation rates (heavy storm downfall common), flash floods are common. As a result, rain/surface erosion is the dominant erosion process in deserts (NOT WIND as one might expect)

2. Causal Factors of Dryness:

a. Latitudinal Effects of Global Surface Heating/Global Weathering patterns: deserts often associated with lack of vertical air movement or lack of adiabatic cooling... hence no air cooling/no atmospheric condensation.

e.g. Sub-tropical latitude deserts such as Sahara, Arabian, Australian.

(1) Result of semi-permanent high pressure systems

(2) High level temperature inversions

b. Orographic/Rain Shadow Effects: on leeward sides of high mountain ranges or in remote continental interiors, precipitation is concentrated on upwind side of mountains, water condenses as air rises over mountains, leaving dry air moving over leeward side, creating desert conditions.

e.g. interior of Pacific Northwest, Mohave desert of

California.

c. Lack of significant vegetative cover (associated with inhospitable climate lacking water). Plant species dominated by succulents (waxy leaves/stems to reduce evapotranspiration: e.g. yucca, aloe, cactus), and short brushy plants with small leaves and long tap roots (e.g. sage brush, live scrub oak)

3. High Landscape erosion Potential: associated with lack of vegetative cover, intense rainfall events, flash floods, weathering, all couple together to present erosion potential.

a. wind vs. water as erosion agent: although wind is a significant factor in desert conditions, water is still the dominant agent of erosion capable of moving larger fragments and quantities of sediment at any given instant.

b. Dry gulches, arroyos, and sediment laiden streams common in desert regions.

4. Weathering- Physical weathering predominates (chemical weathering is at minimum in absence of water) with such processes as salt wedging, thermal exansion, frost wedging, and plant rooting. Generally much slower weathering process than in humid (chemically dominated) terrains.

5. Poor soil development- pedogenesis is generally limited in arid areas but distinctive nonetheless. Salts and pedogenic carbonate development is common in arid soils... Often thin and lack extensive organic matter.

6. Impermeable surface layers possible- in the form of bedrock, hardpans and salt beds. Results in much surface runoff and little infiltration.

7. Sand- desert sand generated during the physical weathering process, as opposed to clay dominated soils in humid/chemically weathered areas. Sand can be readily washed by surface runoff and is in the size range applicable for wind transport.

8. Drainage Patterns- Dominated by ephemeral streams, flowing either seasonally or during storm periods. Large volumes of sediment tend to be transported short distances during storm rainfall events.

9. Closed or internal drainage basins are common in desert regions as opposed to open drainage basins in humid areas. Due to ephemeral nature of stream

discharge due to high evaporation rates and infiltration.

II. GLOBAL DISTRIBUTION OF DESERT ECOSYSTEMS

Desert and Steppe conditions cover upwards of 25-30% of total continental land area forming the largest component of all climatic regimes.

A. Subtropical Deserts at latitudes near or above the Tropics of Cancer and Capricorn.

1. Tropic of Cancer: includes Sahara Desert of N. Africa, the Arabian Desert of the Middle East.

2. Tropic of Capricorn: includes much of Australian interior, and interior Pampas of Argentina.

a. Atmospheric Pressure Differential: derived from unequal heating of earth's surface by solar radiation

(1) Equator: direct radiation, high temp., air heating

(a) warm air rises and moves poleward toward cooler air masses

(b) Cool polar air moves toward equator replacing warm air = circulation cells

(2) Air moving poleward gathers faster than can escape toward poles ---- subtropical high pressure belts

(a) High pressure pushes warm air downward and back toward equator forming Trade Winds

(b) Warm descending air absorbs moisture to create drying effect producing subtropical desert belts of world

B. Mid-latitude Deserts: the Gobi Desert of central Asia (Mongolian) and the Western interior of the United States.

C. Desert Facts and Figures:

1. Largest Desert: Sahara of Northern Africa (10% of total desert area)
2. Sandiest Desert: the Arabian Desert of Arabian Peninsula
3. Hottest Temperature Recorded: 136 degrees F at Libya,

1922, Sahara Desert

4. Greatest 1 day temperature fluctuation: 100 degrees F in Algeria, N. Africa (1927), Sahara Desert
5. Highest Annual Avg. Temperature: 94 degrees F in Ethiopia, Sahara Desert
6. Least Annual Average Precipitation: 0.03 inches in Arica, Chile (coastal Chile and Peru form some of the driest desert areas on earth)

III. FLUVIAL PROCESSES IN DESERT/ARID REGIONS

**Running water is the most important agent of erosion and transportation in desert landscape development.

A. Erosional Characteristics:

1. Rain splash, sheetwash, rilling and flashflooding is common in surface drainage process owing to lack of vegetative cover.

2. Although sporadic, intense rainfall episodes result in great volumes of sediment being mobilized in a relatively short period of time.

3. Stream gradients may be steep but ephemeral nature of flow results in unpredictable imbalance between erosion, transporation and deposition.

   a. Streams rapidly become choked with sediment during concentrated flow/flood events.

   b. Sediment may be rapidly moved and stored under sporadic flow conditions

4. Drainage basins tend to be closed (i.e. not through flowing) with internal drainage and basin sedimentation. This follows in that the general lack of water does not allow extensive through flowing drainage.

5. Desert drainage systems tend to be bedload dominated by coarse sand and gravel, finer silts, clays and sands are readily transported and removed from the sediment population by the sorting action of wind.

B. Desert Hydrology

1. Dominated by ephemeral streams: streams which only flow during seasonal or storm events. Most of the time these drainages exist as dry washes aka arroyos or wadis.
   a. Ephemeral streams comprise 99% of all desert drainages, flowing perhaps only several hours to several days out of the year.

2. Exotic streams = perennial streams that flow year

round through the desert, but these are relatively rare and sustained by water with headlands outside of the desert region in a more humid environment.

e.g. The Nile river with its headlands in the East African rift valley of Kenya and Uganda, which flows north to the Mediterrannean through Sudan and Egypt (both in Sahara Desert regime)

a. Overall flow/discharge of the river decreases in a downstream directions due to infiltration into the streambed, cultural useage, evaporation etc.

3. Lake Basins: perennial lakes uncommon in desert, but dry lake beds are quite common, and associated with the closed nature of drainage basins.

a. Playa lakes- dry lake beds, are epemeral in nature and may periodically contain water, subsequently subject to high evaporation rates

(1) Salt flats: playa lakes in which the water contains an appreciable amount of dissolved salts, upon evaporation the salts precipitate on the lake floor.

b. Pluvial Lakes: perennial lakes found in some desert areas (e.g. Great Salt Lake, Pyramid Lake of Nevada) that are remnants of larger lake bodies that formed in past, more humid climates of the Pleistocene.

C. Fluvial Erosional Desert Landscape Features

1. Fluvial Erosion is the dominant landscape modification process in deserts, the high rates of mechanical/physical weathering by the fluvial process in desert landscape is responsible for large amounts of landscape modification.

a. Differential Eroision- the differential erodibility of different rock types under desert-fluvial conditions. (e.g. quartz sandstone is more resistant than shale to weathering). Differential erosion process results in resistant rock units standing out in relief and less resistant rock units are weathered back.

2. Butte/Mesa Desert Topography: a result of differential erosion with resistant cap rocks holding up topographic features. Features are found in areas with flat lying sedimentary rock layers with alternating resistances to erosion. Sandstone or perhaps limestone often form resistant cap rocks.

a. Butte- round/oval shaped, flat topped topographic feature

b. Mesa- elongated/table like, flat-topped topographic feature

c. Pinnacles- tower-like spires of rock, erosional remnants formed by cap-rocks.

3. Inselbergs- isolated, resistant rock masses that stand high in relief to surrounding topography.

a. Erosionally resistant rock mass, that stands in relief as more easily eroded material is striped/eroded from the surrounding landscape.

b. Found along mature/dissected mountain fronts in desert southwest

4. Pediments- gently inclined, concave up, ramp that extends outward from a mountain front, found along the lower slopes of mountains in desert regions.

a. Pediments often covered with a mantle of unconsolidated debris, or perhaps wind-blown sediments.

b. Origin of Pediments

(1) Lateral Planation by Streams: thought to be the result of a fluvial planation/chemical weathering process as the mountain front is worn back.

(a) Perhaps the process is more active during more humid climatic periods.

(2) Sheetwash Erosion
(3) Rill Wash
(4) Weathering

5. Badland Topography- intricately rilled and barren terrain in arid regions. Common in areas underlain by horizontal strata of shale and clay formations that are poorly consolidated and subject to rilling and gullying. An extensive network of convoluted rills and gullies forming a "badland" topography.

D. Fluvial Deposition in Arid Landscapes: eroded debris is commonly deposited in form of talus slopes and alluvial deposits on valley floors.

1. Depositional Sites

a. Pediment Zone- "foot of the mountains"-

(1) the zone at base of desert mountain ranges that forms the site of fluvial depostions from mountain canyons. (forms deposition site as the break in slope of streams exiting steep mountain canyons, results in decreased gradient, velocity and subsequent deposition)

b. Intermontane Basins: part of the internal drainage network, low areas between mountain ranges, often site of complex interaction between lake basins, aeolian processes, and fluvial regimes.

2. Depositional Features

a. Pediment Zone

(1) Alluvial Fans: fan-shaped deposit of alluvial debris as mountain stream drainages empty onto the piedmont area.

(a) As the stream leaves the canyon, it abruptly loses discharge velocity, subsequently depositing its load at the mout of the canyon in a fan shape deposit with the apex of fan at canyon mouth.

(b) Complex build-up and channel shifting occurs on the fan to build it outward, upward, and laterally.

(c) Multiple channel distributaries on fan

(d) High Rates of infiltration into gravel, and high rates of evaporation

(2) Size of Alluvial Fan Function of:

(a) Area of drainage basin
(b) climate
(c) lithology of rocks in source area

(3) Bajada- coalescing alluvial fans from adjacent mountain canyons forming a "fan apron" along the mountain front.

b. Intermontane Basins:

(1) Playa lake deposits

(2) Alluvial deposits

(3) Aeolian Deposits: i.e. dune development

IV. AEOLIAN PROCESSES IN DESERT ECOSYSTEMS: WIND PROCESSES

A. Introductory statement: desert winds readily move sediment in sparse vegetative regimes, but the size fraction is generally limited to clays, silts, and fine sand.

1. Wind may seem extensive in deserts, but plays relatively minor role in major landscape modification processes.

2. Wind- related to horizontal air movements with turbulence in air flow paths, and variable velocities common.

3. "Aeolian" processes- are those related to wind (greek root of wind).

4. Driving Force: Solar Insolation + Atmospheric Phenomena

B. Wind Patterns and Moving Air Masses

1. Driving Force

a. Wind: generated by differences in air pressure

(1) High-to-low pressure air flow = "wind"

b. Solar Insolation

(1) Atmospheric Pressure Differential: derived from unequal heating of earth's surface by solar radiation

(a) Equator: direct radiation, high temp., air heating

i) warm air rises and moves poleward toward cooler air masses

ii) Cool polar air moves toward equator replacing warm air = circulation cells

(2) Local Winds

(a) E.g. land heating during day, air warms up and into motion

C. Aeolian Erosion Processes:

1. Deflation- general movement of loose particles by shear force in suspension or by rolling along ground surface.

a. Blow outs or Deflation Basins: selected areas subject to appropriate wind processes, which are selective deflated on finer grain-size fractions of loose unconsolidated ground sediment.

2. Abrasion- i.e. sandblasting effect eroding and setting additional sediment into motion.

a. Rock pitting, etching, faceting, and polishing.

b. Ventifacts- polished and abraded stones on desert floor.

(1) Sand blasting effect

c. Desert Pavement- a layer of coarse gravel and boulders left stranded on desert floor as wind selectively deflates finer grain sizes out of area.

(1) desert varnish- a dark shiny coating consisting ofiron and maganese oxides coating desert pavement.

(a) Builds up through time, can provide a relative dating tool. Perhaps some luck with carbon 14 dating?

(b) Desert varnish may be related to bacteria build up.

D. Aeolian Transportation:

1. Bedload: coarse sand moved along ground surface through saltation process.

a. Saltation: trajectory particle motion, bouncing and air trajectory motion

b. Impact Creep: larger particles impacted by saltating particles, resulting in pushing or creep along desert floor

2. Suspension Load: finer sand, silt, and clay particles carried above the ground surface in air turbulence.

a. Sand Storms/Dust Storms: sediment in suspension anywhere from several inches to several feet, to 100's of feet above ground surface.

E. Aeolian Deposition:

1. Finest silt and clays are often carried furthest out of desert basin, while coarser sand is deposited within

the desert floor. Generally sand is deposited at any point where wind velocity decreases either naturally or via shadow/pockets.

2. Sand Sheets: sheet sand deposit on desert floor

3. Sand Dunes: mounded piles of windblown sand deposited on desert floor. May be found in extensive dune fields, on playas, or on bedrock surfaces.

   a. Ergs- "sea of sand", a large sand dune complex perhaps covering 10's to 100's of square miles. Source of sand may be associated with more humid recent periods where weathering rates were much higher.
   b. Dune Migration and Deposition: once dunes take form, they often change shape and migrate about on desert floor depending on primary wind patterns.

      (1) Classic Dune Profile: gently sloping stoss side (up wind side) of 10-15 degrees, crest or top of dune, and steeply inclined (32-25 degrees) leeward side or "slipface".

         (a) Slipface- steep leeward side of dune (30-35 degrees), Sand generally saltates up stoss side, and is deposited on leeward side at slip face in the dune shadow. Avalanching common on slipface forming high angle cross-bedding.

      (2) Dune Migration: result of slip face advance and lee side erosion

   c. Sand Dune Types: classification based on shape and pattern of dunes

      (1) Barchan Dunes: solitary crescent shaped dunes with their tips pointing downwind (i.e. horns point downwind). Steep leeward slipface on on concave side of dune.

         (a) very fast moving dunes found in areas of moderately limited sand supply,

         (b) strong unidirectional winds

         (c) sparse vegetation

      (2) Transverse Dunes: essentially a series of interconnected barchan dunes connected by a sinuous crest.

         (a) Crest oriented transverse to wind direction,

(b) Found in areas of greater sand supply than barchan dunes,
(c) Strong unidirectional winds.

(3) Longitudinal Dunes or Seifs- elongated ridges of sand in which the dune crest is oriented parallel to the wind direction.

(a) Thought to be associated with modest sand supplies
(b) Variable wind direction: two dominant wind directions within 90 degrees of one another.

(4) Parabolic- similar to barchans but in opposite orientation--crescent-shaped dunes with steep lee side on convex portion, with horns pointing upwind.

(a) Found in areas where vegetative growth anchors the dunes with subsequent blowout of stoss-side central portions.

(5) Star Dunes: three or more sharp-edged ridges extending radially from a high central peak

(a) Product of multidirectional wind

d. Loess- wind-blown silt and clay, generally lacks stratification, with great cohesion within depositional unit.

(1) Often found at edges of desert basins or on margins of glacial outwash areas.

(a) E.g. Palouse Loess hills of eastern Washington