

G422/522 Advanced Topics / Fans
The Influence of Climate and Tectonics on Fan Development

I. Introduction

A. Fans

1. storage compartments for sediment records
2. stratigraphic record of process
 - a. depositional style
 - b. erosional style
3. Morphology and internal stratigraphy provide record of tectonic and climatic variables

B. Influence of Tectonics

1. Classic: Fault Bounded Mountain Fronts
 - a. Basin Subsidence
 - b. Range Uplift
2. Tectonic Accommodation Space / Relief
 - a. Rates of Basin Subsidence
 - b. Relief / Mountain Watershed Development
 - c. Local Base Level Change
3. Tectonism - produces relief and accommodation necessary for fans to form

C. Influence of Climate (modulation of hydrologic regime)

1. controls watershed discharge and stream power
2. controls weathering rates and sediment production
 - a. vegetation control
 - b. hillslope stability
3. Local vs. Region climatic signals

D. Classic Sedimentary Basin Models

1. Steel and others, 1977
 - a. "major control on most sedimentation is tectonic"
 - b. Coarse-grained fan facies in tectonically active zones
 - (1) coarse-grained facies associated with fault-bounding tectonic activity
 - (2) fine-grained facies associated with tectonic quiescence
 - c. Early sedimentation models ignored climate factors
2. Blair and Bilodeau, 1988
 - a. Coarse-grained facies prograde into basins during tectonic quiescence
 - b. Fine-grained facies associated with fault-bounding tectonic activity

II. Late Pleistocene Climate Reconstruction of SW U.S.

A. Record

1. Pluvial Lake Development during last glacial
2. playas during current interglacial

- B. Controls on SW U.S. Climate
 - 1. Position of Polar Front / polar jetstream
 - 2. Seasonal behavior of Polar jetstream
 - a. "meridional" = seasonal migration of polar front
 - (1) northward migration = incursion of warm, moist tropical air
 - (a) present-day = "monsoonal" climate
 - i) summer storm systems
 - b. "zonal" = stable polar front
 - (1) strong, stable westerly airflow off mid-latitude Pacific

- C. Pleistocene glacial climates
 - 1. General glacial climate characteristics in SW U.S.
 - a. forcing of polar front to south / southwest
 - b. cooler temperatures (3-8 degree C cooler)
 - (1) decreased evaporation
 - c. increased precipitation (60-300% of present day)
 - 2. Southward displacement of jet stream with strongly zonal, westerly air flow
 - a. Pluvial Lakes
 - (1) reduced evaporation
 - (2) consistent storm systems

- D. Holocene Climates
 - 1. Meridional air flow
 - a. seasonal flux of polar front
 - 2. Monsoonal climate
 - a. penetration of tropical air into the SW during summer
 - 3. Fan Activity / climate conditions
 - a. summer thunderstorms / localized
 - b. late summer tropical storm systems / cyclones
 - c. Geomorphic Fan Activity
 - (1) requires precipitation events / sediment delivery events

III. Vegetational Response / Hillslope Stability

- A. Paleoclimate indicators
 - 1. pine-fir = subalpine / montane forests
 - 2. Pinyon-Juniper = semi arid dry climate systems
 - 3. desert shrub = desert conditions
- B. Base Model
 - 1. Stream Power / Runoff > Sediment Supply = fan degradation
 - 2. Stream Power / Runoff < Sediment Supply = fan aggradation
 - a. Fan Aggradation a result of hillslope erosion in response to < in vegetative cover and > summer storm activity (e.g. Holocene climate forcing)

IV. Class Discussion

- A. How to test for tectonic vs. climatic signals in alluvial fan records?

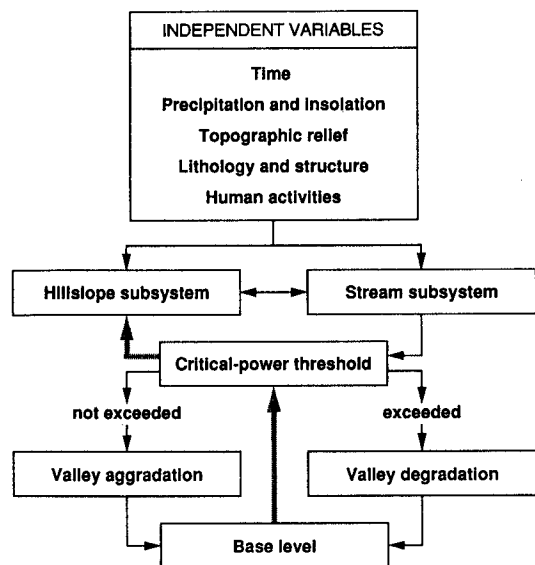


FIGURE 1.1 Basic elements of a fluvial system. Dashed arrows indicate feedback mechanisms.

TABLE 1.1 Partial list of independent and dependent variables of a fluvial system for a time span of more than 1000 years (1 ky).

Independent Variables	Dependent Variables
Climate (source of kinetic energy)	Drainage basin area
Total relief (function of uplift; determines potential energy)	Hillslope morphology
Base level at mouth of drainage basin	Drainage net
Lithology	Soil-profile development
Geologic structure (fractures, joints, shears, folds)	Vegetation
Human activities	Fauna
	Water and sediment yield from hillslopes
	Stream-channel slope, patterns
	Water and sediment discharge from basin ^a
	Stream-channel scour and backfill ^a
	Human activities ^a

^aApplicable only for the largest flood events for the time span used in this table.

1.2 Variables of Fluvial Systems

The basic components of a fluvial open system are shown in Figure 1.1. Selected independent variables are listed at the top of the diagram. Fluvial systems may be divided into hillslope and stream subsystems, and even plant communities and soil-profile catenas may be considered subsystems. Stream subsystems have two disequilibrium *modes of operation*, aggradation and degradation, and one equilibrium mode (Section 1.3) operative during periods of no net change in variable interactions. An erosional-depositional threshold (the threshold of critical power) separates the modes of aggradation and degradation (Section 1.4). Changes in basic components of fluvial systems result in additional changes in the components through feedback mechanisms (Sections 1.2, 1.3).

A variable is an object or an attribute that varies in time, space, or both. Variables such as climate and lithology have little relation to other variables in a drainage-basin fluvial system and may be regarded as *independent variables* (Table 1.1). Independent variables exert primary control on fluvial systems, and may be thought of as external because they are partly or entirely the result of processes outside the fluvial system. Geologic structure is in part dependent on lithology, but for the purposes of landscape studies may be regarded as an independent variable. Most *dependent variables* may be thought of as internal because they are the result of process interactions within the system. Dependent variables—for example, vegetation—are controlled by both independent variables and other dependent variables. Hillslope morphology and drainage net may be considered independent variables for time spans on the order of 0.1 ky. Drainage basin area is an independent variable for time spans of less than 1 ky because it generally is constant during such short geologic time spans if resistant rocks underlie the basin.

Lithology and petrologic structures associated with rock formations undergo minimal changes with time, whereas climate and relief may change continually. Relief is a function both of uplift,

TABLE 2.1 Classification of climates.

Precipitation		Temperature	
Class	Mean Annual (mm)	Class	Mean Annual (°C)
Extremely arid	<50	Pergelic	>0
Arid	50-250	Frigid	0-8
Semiarid	250-500	Mesic	8-15
Subhumid	500-1000	Thermic	15-22
Humid	1000-2000	Hyperthermic	>22
Extremely humid	>2000		
Class	Seasonality Index (Sp) ^a	Class	Seasonality Index (St) ^b (°C)
Nonseasonal	1-1.6	Nonseasonal	<2
Weakly seasonal	1.6-2.5	Weakly seasonal	2-5
Moderately seasonal	2.5-10	Moderately seasonal	5-15
Strongly seasonal	>10	Strongly seasonal	>15

^aPrecipitation seasonality index (Sp) is the ratio of average total precipitation for the three wettest consecutive months (Pw) divided by average total precipitation for the three driest consecutive months (Pd).

$$Sp = \frac{Pw}{Pd}$$

^bTemperature seasonality index (St) is mean temperature of the hottest month (Th) minus mean temperature of the coldest month (Tc), in °C.

$$St = Th - Tc$$

A review of the nature of present and past climates will underscore the potential of the region for these studies.

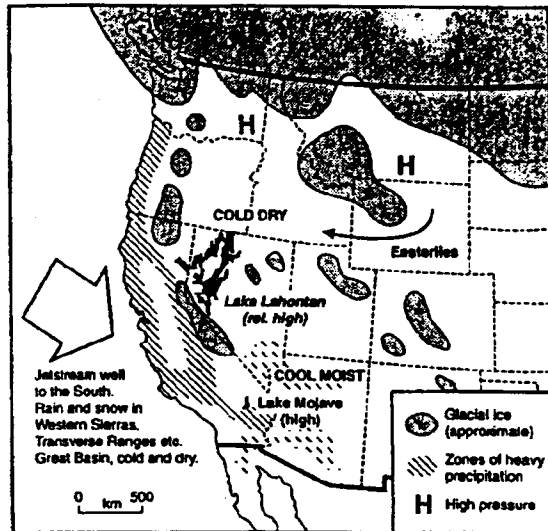
2.1.1 REGIONAL CLIMATOLOGY

Before examining the nature and effects of past climates, we need to understand the present climate and the spatial boundaries between regions of different dominant atmospheric circulation. Weather in the southwest deserts can vary abruptly. Monotonous warm, dry weather associated with mid-latitude subsiding airmasses is interrupted by winter storm fronts from the Aleutian low-pressure center in the northern Pacific Ocean, by occasional outbursts of polar continental air, and by the sum-

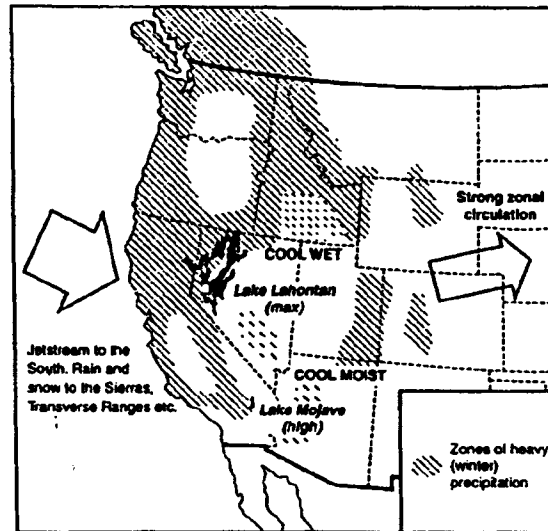
mer monsoon (Bryson & Lowry, 1955). The monsoon derives tropical moisture from both the Gulf of Mexico and the Pacific Ocean through the Gulf of California (Hales, 1974). Casual desert visitors decry an apparent lack of seasons, but the relative influence of these types of circulation define different seasonalities for local climates that greatly influence plant communities and geomorphic processes in the Sonoran, Mojave, and Great Basin deserts.

D. L. Mitchell (1976) divided the western United States into climatic regions on the basis of dominant summer and winter airmasses. He divided climatic regions using *equivalent potential temperature*, which is calculated from month's mean of maximum temperature, relative humidity,

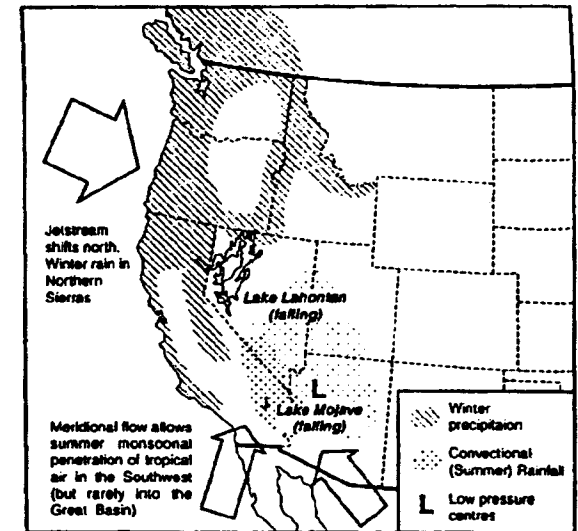
18ka (Last Glacial Maximum)



14 - 11ka

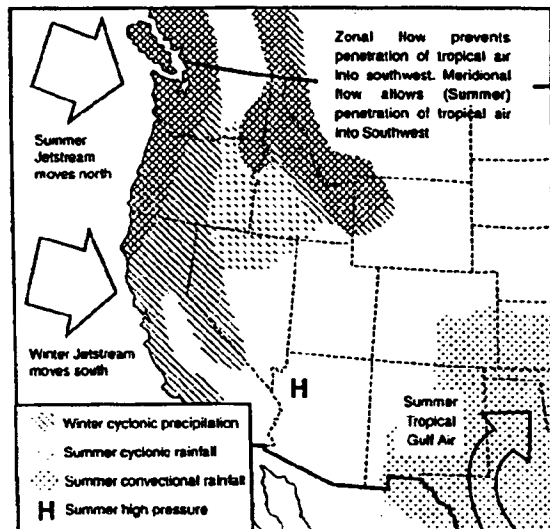


11 - 8ka

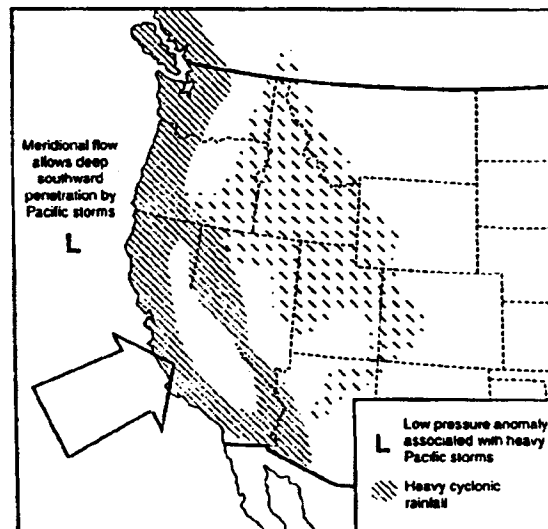


Modern Conditions

Modern 'Dry Conditions'



Pacific Winter Storms



Summer 'Monsoonal' Storms

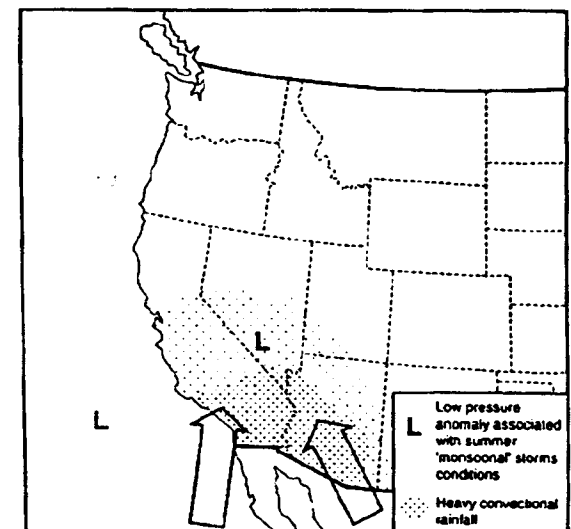




FIGURE 2.10 Oblique aerial view of the piedmont east of the Gila Mountains, Arizona. The ridge-and-ravine topography of the highly dissected Q1 alluvial geomorphic surface is mainly in the foreground and right background. The smooth black desert pavements of the Q2 surfaces are mainly in the right middle ground; the moderately dissected Q2b surface is the most widespread, but Q2c and Q2a surfaces also are present. The Q3a, b, and c surfaces to the left of center are undissected by streams originating on the surfaces and have a bar-and-swale topography that gives a plumose texture to the aerial view. The Q4 surfaces are associated with 3- to 7-m-high trees whose growth is restricted to the active washes. Photo by William C. Tucker. (Figure 2.20 is a vertical aerial view of this piedmont; Figure 2.24 is a map of the alluvial geomorphic surfaces.)