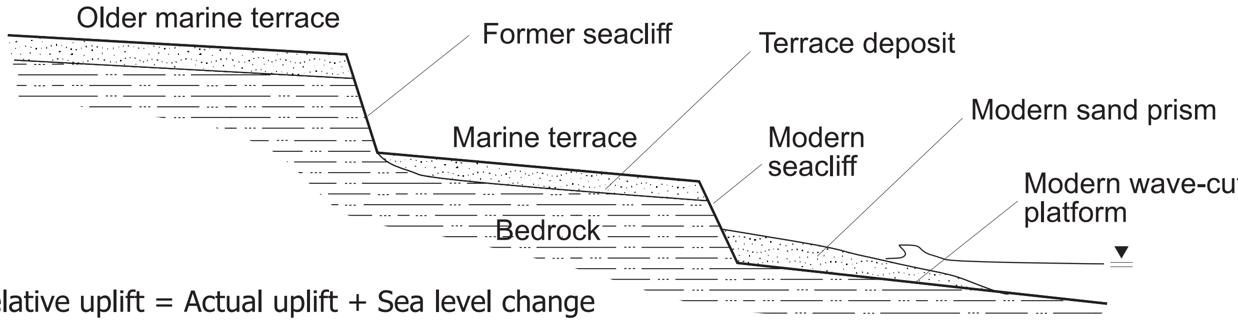
A Primer on Coastal Bluff Erosion

Mark J. Johnsson, Staff Geologist, California Coastal Commission

Seacliffs and coastal bluffs are formed by a rapid uplift of the shore relative to sea level. When the relative uplift of the shore is slow or zero, a wave-cut terrace is formed



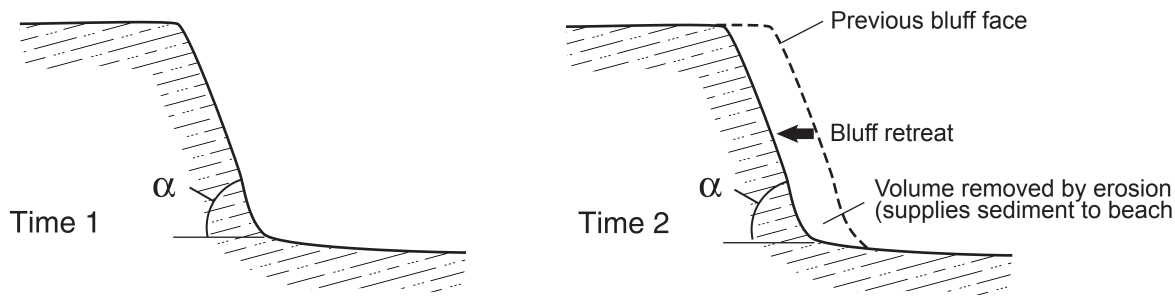
Relative uplift = Actual uplift + Sea level change

☐ Relative uplift occurs when:
☐ ☐ 1) Shore rises; sea level falls, is stable or rises at a lower rate than shore; or
☐ ☐ 2) Shore is stable; sea level falls; or
☐ ☐ 3) Shore falls; sea level falls at a faster rate
☐ Relative uplift is zero when shore and sea level rise or fall at the same rate (which may be zero)☐☐

The term "coastal bluff" refers to the entire slope between a marine terrace or upland area and the sea. The word "seacliff" refers to the lower, near vertical portion of a coastal bluff. Erosion of the entire seacliff-bluff system must be considered together.

Coastal Bluff Retreat

The question of how slopes erode is one of the oldest problems in geomorphology. Much argument has revolved around models calling on parallel slope retreat, versus slope erosion by flattening - the answer may lie somewhere between the two extremes. In any case, steep bluffs tend to erode parallel to the bluff face at an equilibrium stability angle, α. In unconsolidated materials this angle is known as the "angle of repose." α is a function of material strength. A bluff will erode through various mechanisms to establish and maintain the characteristic slope angle for the material of which it is composed.



If a bluff becomes oversteepened (slope angle greater than α) through non-equilibrium erosion (such as marine erosion at the toe of a seacliff), it will be unstable and will tend to erode back to α - perhaps through sudden collapse (landslide, rock fall)

If the rate of erosion as well as α are different for the different materials making up the bluff, then the bluff will develop a bench (if erosion is faster in the upper unit) or overhang (if erosion is faster in the lower unit)

Because material is removed most rapidly from bluff tops and tends to accumulate at the base of bluffs, the overall steepness of the slope appears to decrease through time; but the active part of the slope retreats at the long-term equilibrium stability angle, α, despite short-term departures from this angle.

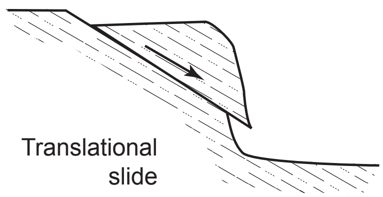
Mechanisms of Bluff Erosion

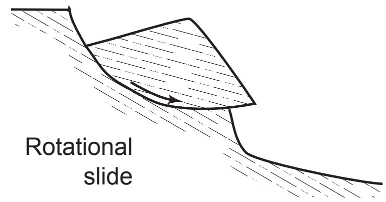
Sheetwash: Material loosened and carried down bluff by water flowing over its face as a film or sheet

Gullying and rilling: Organization of water flowing over bluff into distinct drainage systems or gullies; concentrates flow energy in narrow portion of bluff, increasing its erosive capacity

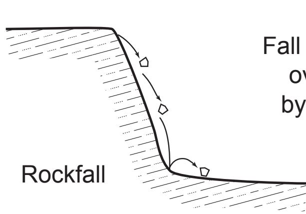
Creep: On shallow slopes consisting of poorly consolidated material, sediment may move downslope slowly as a coherent mass

Sudden bluff collapses may take several forms:

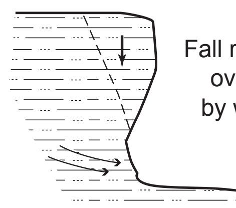




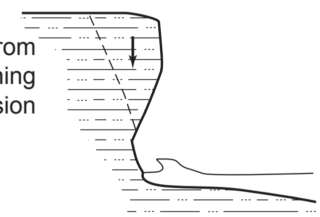
Falls: Vertical (or nearly so) movement of coherent masses of material



Fall resulting from oversteepening by ground water sapping



Fall resulting from oversteepening by wave erosion

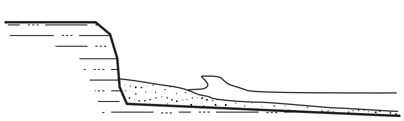


Erosional Agents Involved in Bluff Erosion

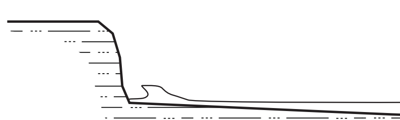
Surface runoff: Promotes sheetwash, rilling and gullying
Ground water: Promotes creep, facilitates slumps and slides
Marine erosion (wave attack): Oversteepens cliffs (above equilibrium stability angle), facilitating slumps, landslides and falls. Exacerbated by wave-driven projectiles (logs, cobbles, etc.)
Wind erosion: Usually less important, but may erode cohesionless sands
Other agents may be important in some situations: e.g., slaking through alternate wetting/drying; wedging by salt crystals, etc.

Role of the Beach

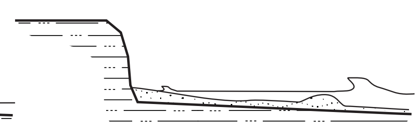
Affects only marine erosion



Protective beach
Wave energy partly absorbed by beach



No beach
Wave energy delivered to bluff



Offshore bar or reef
Wave energy partly absorbed far offshore

Key issues affecting mechanisms and rate of bluff erosion

- Material strength
  - Rock type
  - Cementation
  - Fractures and orientation
  - Weak planes (e.g., clay seams)
  - Clay content (expandable clays)
- Bluff/beach geometry
- Wave energy
  - Aspect and exposure
  - Local effects (e.g., wave refraction)
  - Protective beach
  - Offshore bars or protective devices
- Surface runoff over bluff
- Presence/absence of ground water

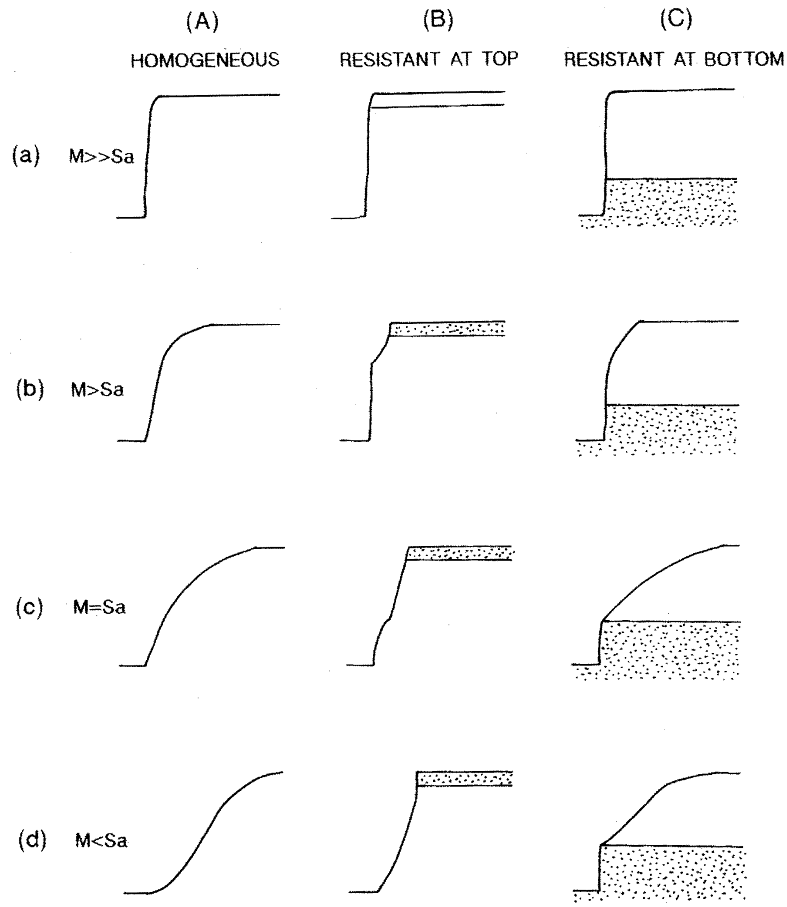
Bluff shape reflects the relative roles of surficial, marine, and ground water erosion acting on the materials making up the bluff

Composite Bluffs

Many coastal bluffs in California are composed of more than one type of material; commonly a poorly consolidated marine terrace overlying a better consolidated sedimentary bedrock.

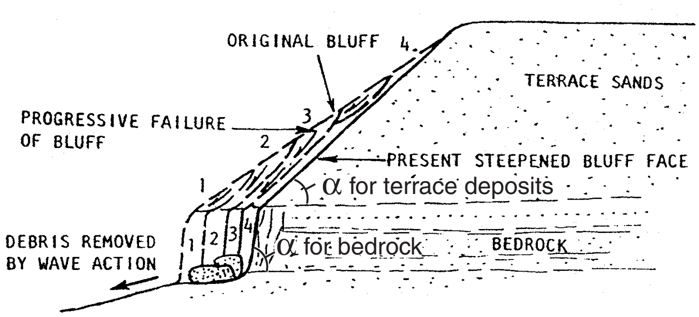
Erosion of seacliffs is through a combination of marine and subaerial processes. The relative importance of each of these processes, together with the relative durability of the various rock layers comprising the bluff, determine the overall geometry of the bluff.

The twelve profiles to the right reflect varying positions of durable units and variable relative importances of marine (M) versus subaerial (Sa) erosion.



(from Emery and Kuhn, 1982)

Paired, Episodic Failures



Composite bluffs commonly fail in paired sets: an initial block failure of a resistant lower unit leaves the weak upper unit unsupported, which will fail as a rotational slide or slump soon thereafter. The process is repeated episodically.

(modified from Leighton and Associates 1979)

POLICY ISSUES AND OPTIONS

Building in areas safe from bluff erosion - establishing setbacks

Bluff retreat rates:
- Represent long-term averages useful over economic lifespan of development; useless over shorter timespans due to episodic nature of bluff retreat
- Should be based on long time series of data, including both relatively quiescent periods in mid-twentieth century, and more active period beginning around 1980 (including El Niño winters of 82-83 and 97-98).
- Data sets: Aerial/satellite photography, topographic surveys, GPS surveys, LIDAR
- Setback = (annual average retreat rate) x (economic lifespan of development) + (buffer)

Slope stability analysis:
- Based on a quantitative model of stability of slope
- Establish likelihood of sudden (catastrophic) failures; currently largely limited to landslide hazards
- Data sets: material strength (cohesion, friction angle) and weight; slope geometry
- Setback = area behind the 1.5 factor of safety line (i.e., forces resisting landslide movement are 1.5 times as great as forces driving landslide)

Remedial measures - alternatives analysis

Control surface runoff:
- Direct runoff away from slope; regrade top of bluff, install berms and swales, extend drainage culverts down face of bluff
- Collect water on bluff face and carry it away through impervious channels/pipes

Control ground water:
- Reduce infiltration: Restrict irrigation, increase hardscape, install clay caps, plug and control rodent burrows
- Lower ground water levels: Install horizontal drains (hydroaugers), pumping wells

Protect base of bluff from marine erosion:
- Establish sand beach, maintain through nourishment
- Offshore structures: groins, submerged artificial reef, breakwaters, etc.
- Seawalls and revetments

Protect overly steep upper bluff:
- Remove and recompact soil; use of geogrid reinforcement
- Upper bluff retaining walls, shotcrete walls, soil nails, tieback anchors, etc.

"Correct" bluff geometry:
- Seacave and notch infills
- Regrade bluff, remove and recompact soil, possibly use of geogrid reinforcement

Negative effects of seawalls and bluff retaining devices

- Fix back of beach; as front of beach moves landward during sea level rise, beach disappears
- Retain sand in coastal bluff which would otherwise have become available to replenish the beach
- Encroach on public beach, reducing area of beach
- May limit vertical and lateral access to beach
- Visual impacts

§30235 of Coastal Act and CEQA require approval of shoreline protective structures only when:

- Required to serve coastal-dependent uses or to protect existing structures or public beaches in danger from erosion
- Designed to eliminate or mitigate adverse impacts on local shoreline sand supply
- The least environmentally damaging alternative available

Some points to bear in mind...

Coastal bluff collapse and retreat are natural erosional processes

Coastal bluff erosion is caused by a combination of processes

Bluff retreat can be stopped or slowed significantly through sufficient engineering

Engineered structures may have negative visual, access, and secondary erosional effects