ESS 326
Introductory Geomorphology

Ways of thinking about the Earth to understand its dynamic surface

http://gis.ess.washington.edu/grg/courses.html

See ESS 326 listings for powerpoints

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Dave Montgomery studies the evolution of topography and the influence of geomorphological processes on ecological systems and human societies. His work includes studies of the evolution and near-extirpation of salmon, fluvial and hillslope processes in mountain drainage basins, the evolution of mountain ranges (Cascades, Andes, and Himalaya), and the analysis of digital topography of Earth and Mars.

What is Geomorphology?

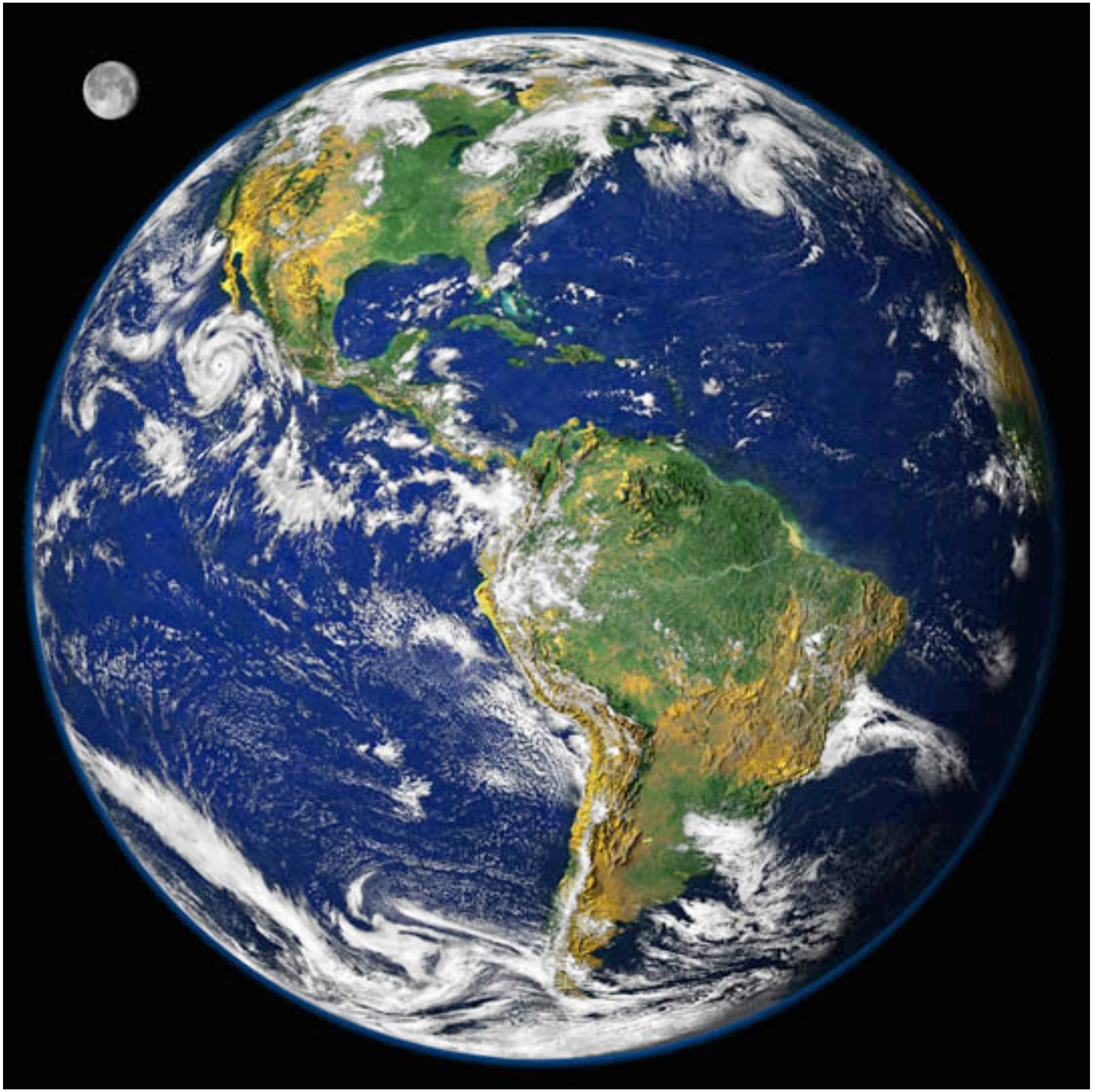
Geomorphology is the science concerned with the form of Earth's surface and the processes that create it.

Origin of the term (from Greek):
Geo = Earth; morphos = form; -ology = science.

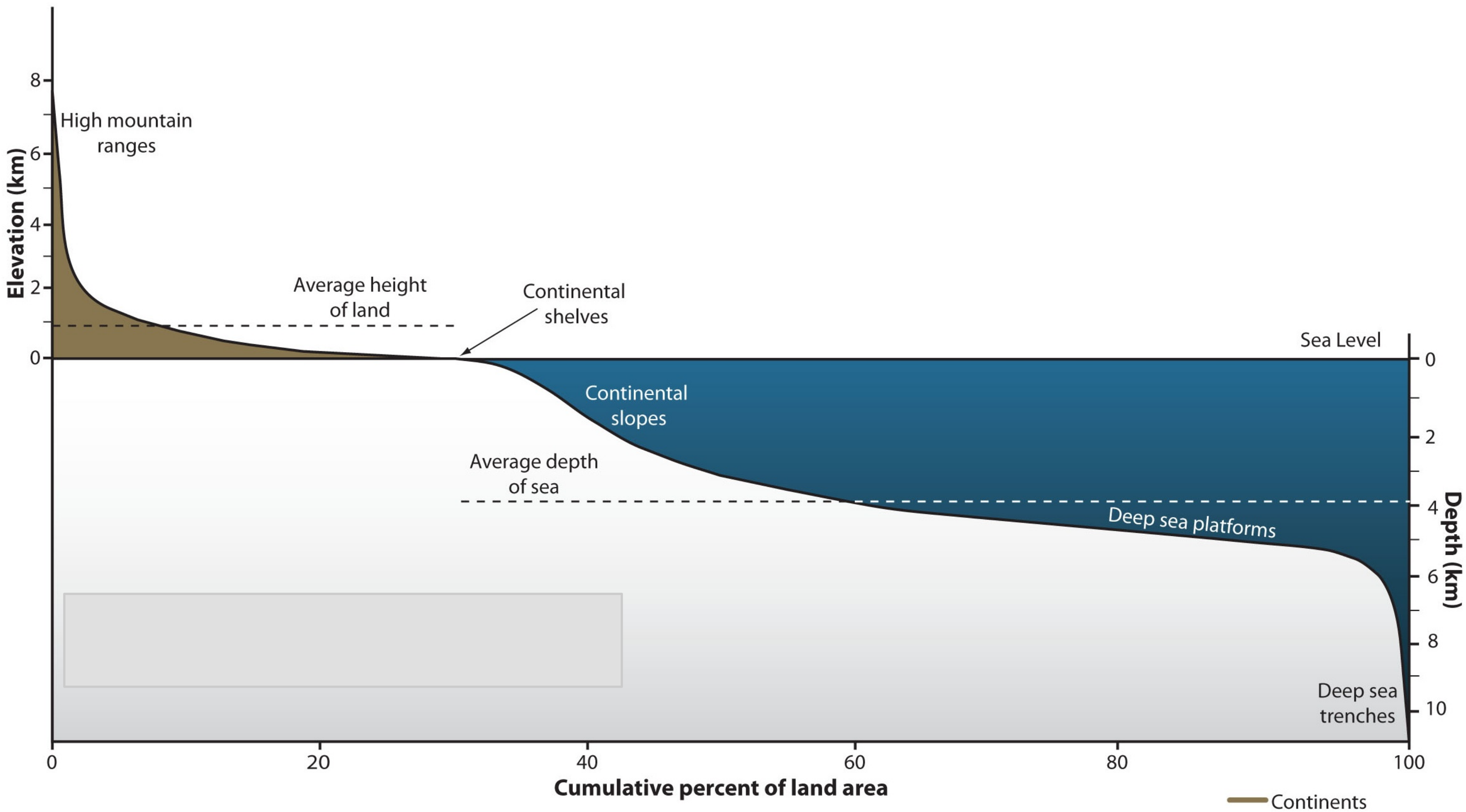
Geomorphology gained widespread recognition as a distinct discipline only after the International Geological Congress of 1891.

Why study geomorphology?

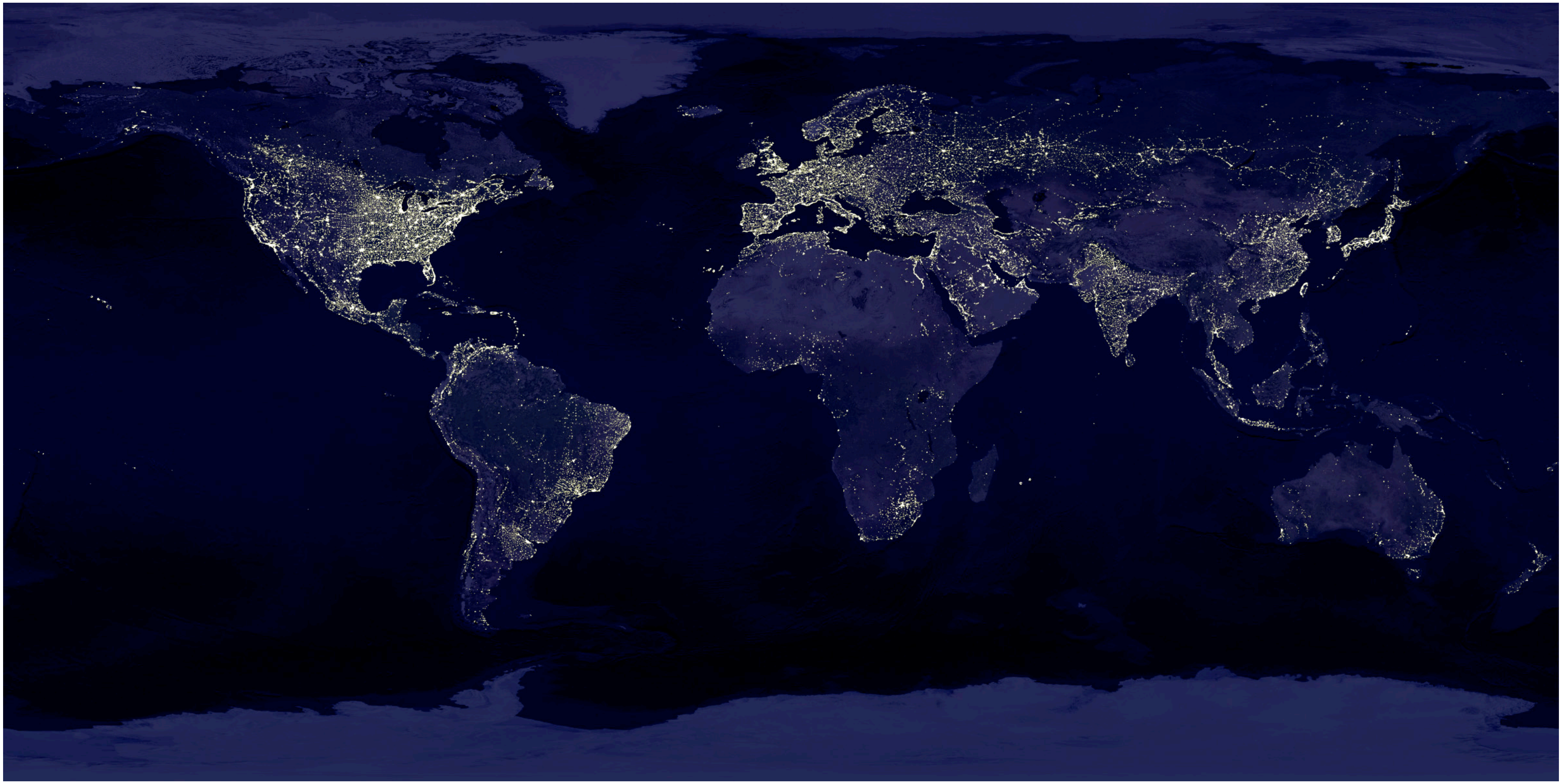
We live on Earth's surface and its dynamic nature shaped the landscapes we call home and from which we derive our living…



Most of Earth's surface is water
Two dominant elevations correspond to ocean basins and continents
Most of Earth's land surface is < 2km elevation

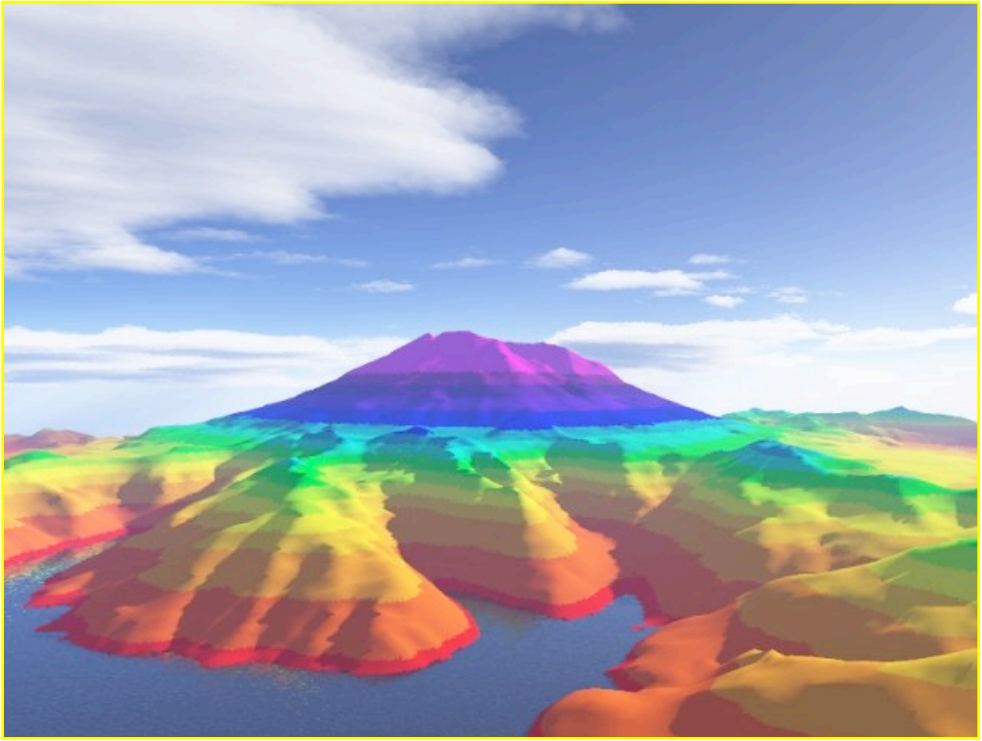


People are becoming a dominant influence on Earth's landscapes and biota.
How do our actions influence the natural systems on which we ourselves depend?

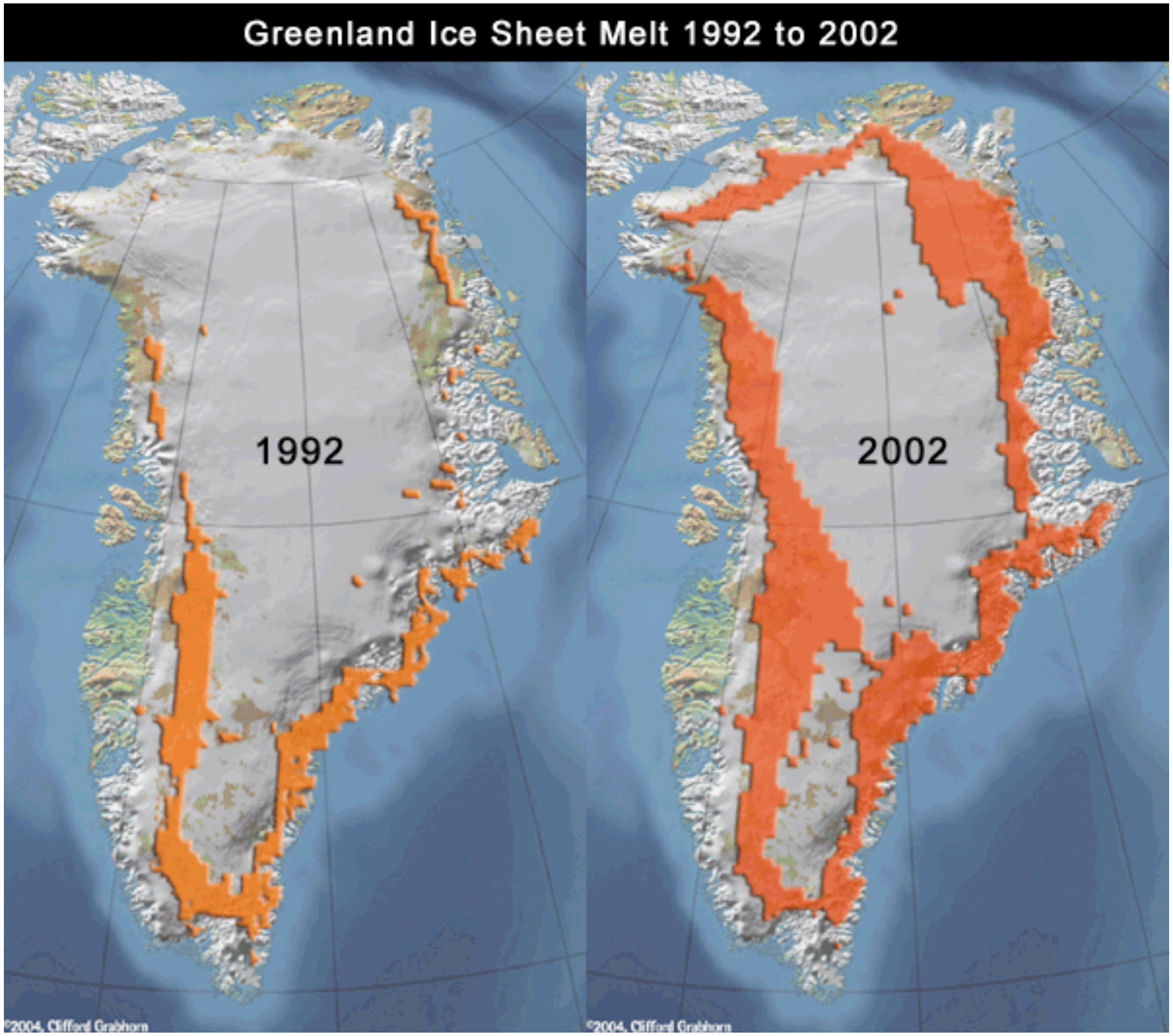


Geomorphology provides new ways of seeing landscapes

How do active geomorphological processes shape landscapes and what are the controls on their actions and effectiveness?



The world is changing … understanding landscape response to climate change requires understanding how landscapes function — and how the pieces interact.



- Motivations for Study of Surface Processes
  - First Wave Climate Science Completed: climate is changing, causes known
  - Second Wave Coming: what are consequences, how respond?
  - Landuse Change even more dramatic
  - Prediction: Need Quantitative Understanding of Processes / Record of Past Conditions/Responses

The study of landforms can be traced back to the works of:

Plato (427-347 BC) - cited human influences on erosion and it's effects on economic productivity.

Aristotle (384-322 BC) - theorized about the origin of streams.

Avicenna (979-1037) - theorized that natural topography could result from the action of running water.

Leonardo da Vinci (1452-1519) - discussed the evolution of topography

The term geology, introduced by Warren in about 1687, originally meant the description and study of either (i) scenery, or (ii) minerals and rocks.

Critical Concepts of Geomorphology

- Agents
  - "that which acts or has the power to act"
  - **Water, ice, wind**…
- Processes
  - "progressive steps by which an end is attained"
  - **Weathering, erosion, transport, deposition**
- Energy
  - Solar, geothermal, gravitational, chemical

Critical Concepts of Geomorphology

- Systems
  - "an assemblage of parts forming a whole"
  - Fluvial, glacial, coastal
- Climate
  - Determines dominant agents
- Time
  - Evolution of landforms/landscapes
- Regionality
  - Physiography

Broad Controls on Land Form

Exogenic versus endogenic processes -- Internal versus external forcing

Exogenic : Processes occuring on the Earth's surface and that generally reduce relief. These processes include weathering and the erosion, transport, and deposition of soil and rocks; the primary geomorphic agents driving exogenic processes are **water, ice, and wind**.

Endogenic : Processes occuring in Earth's interior that create relief by elevating mountains and land masses, and depressing basins and ocean floors. **Tectonic, isostatic, and volcanic** processes dominate the influence of endogenic processes on land form.

Key Forces

Land form is controlled by the interaction of **tectonics, climate and erosion**.

Tectonic processes that uplift topography are rooted in the relation of Earth's crust to deeper circulation and convection in Earth's mantle.

Earth Surface processes that erode and sculpt topography consist of geomorphological, hydrological, and geochemical processes that erode and transport soil, sediment, and rock.

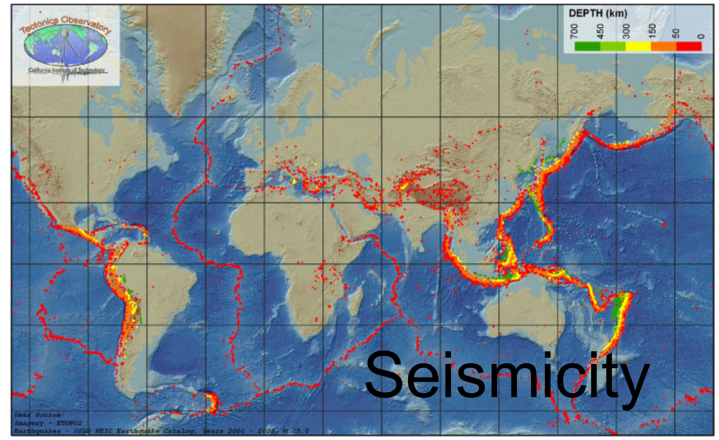
Tectonics

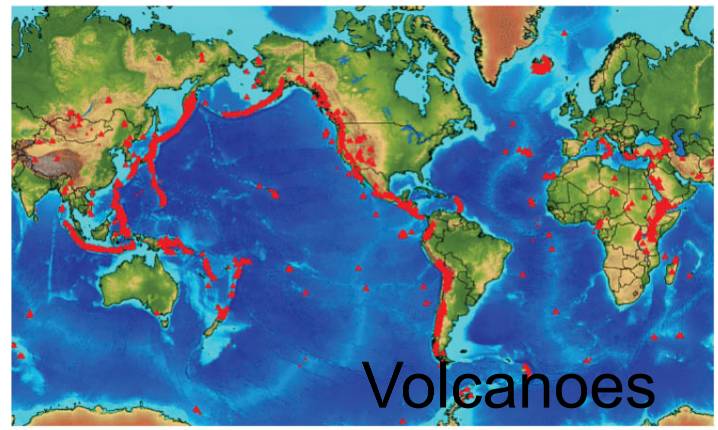
Tectonic processes act both locally and regionally to set the boundary conditions upon which erosional processes act.

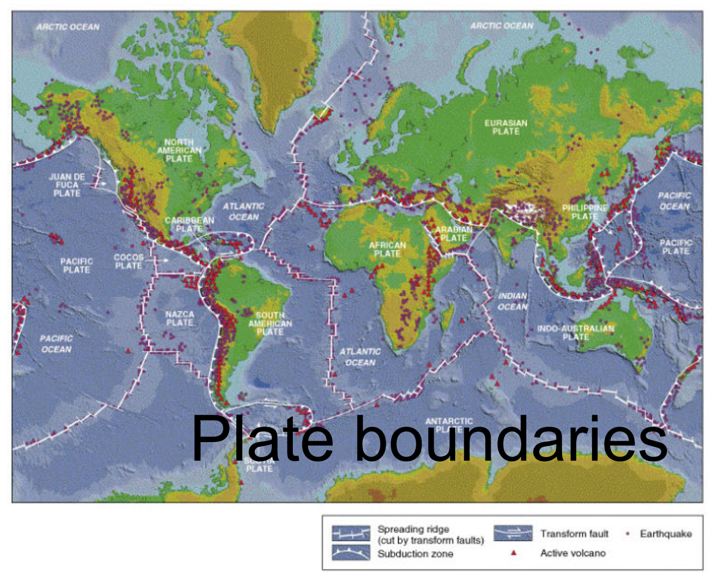
The uplift of a mountain range or the creation of a volcano provides fodder for erosion.

Differences in the style, extent, and rates of tectonic processes can lead to very different land forms.

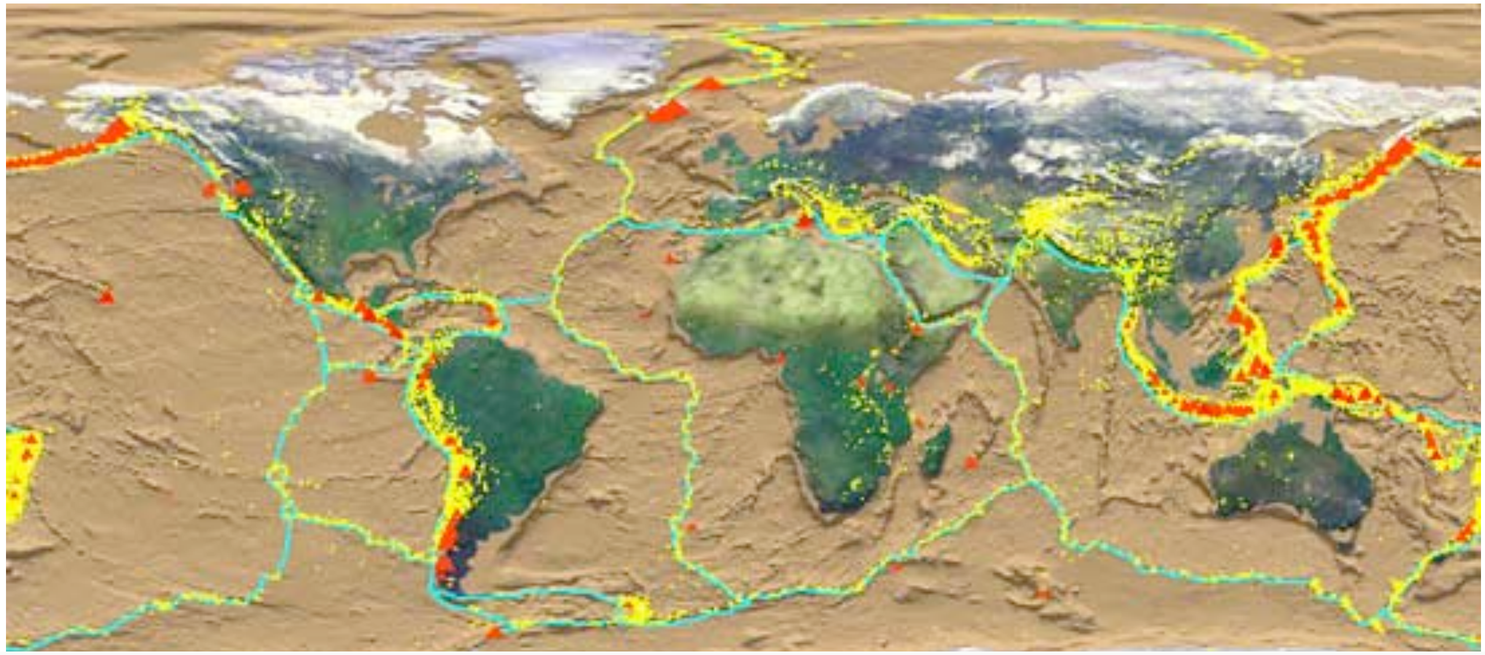
Global patterns of earthquakes and volcanoes outline boundaries to major tectonic plates that correspond to first-order controls on regional physiography



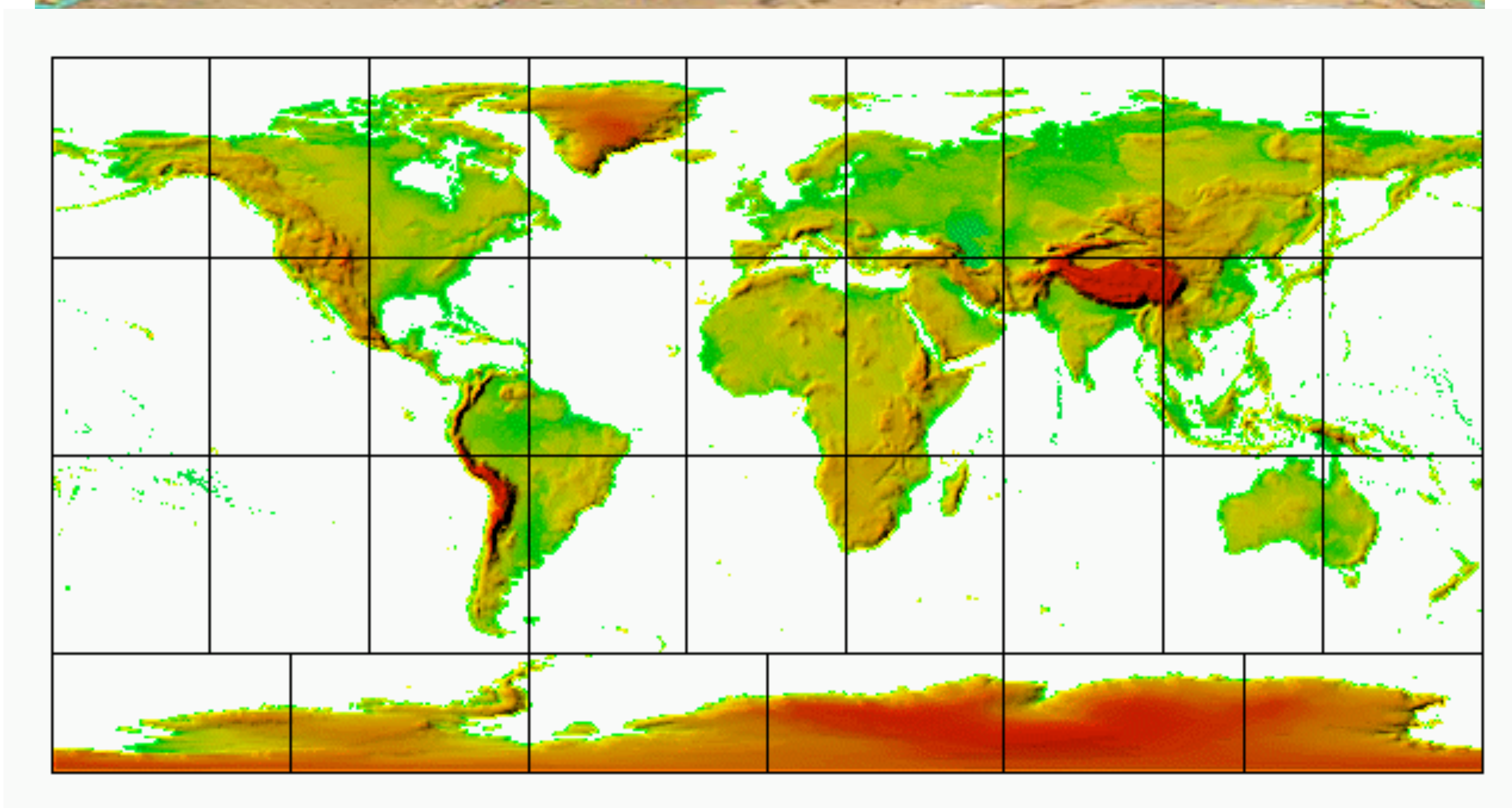




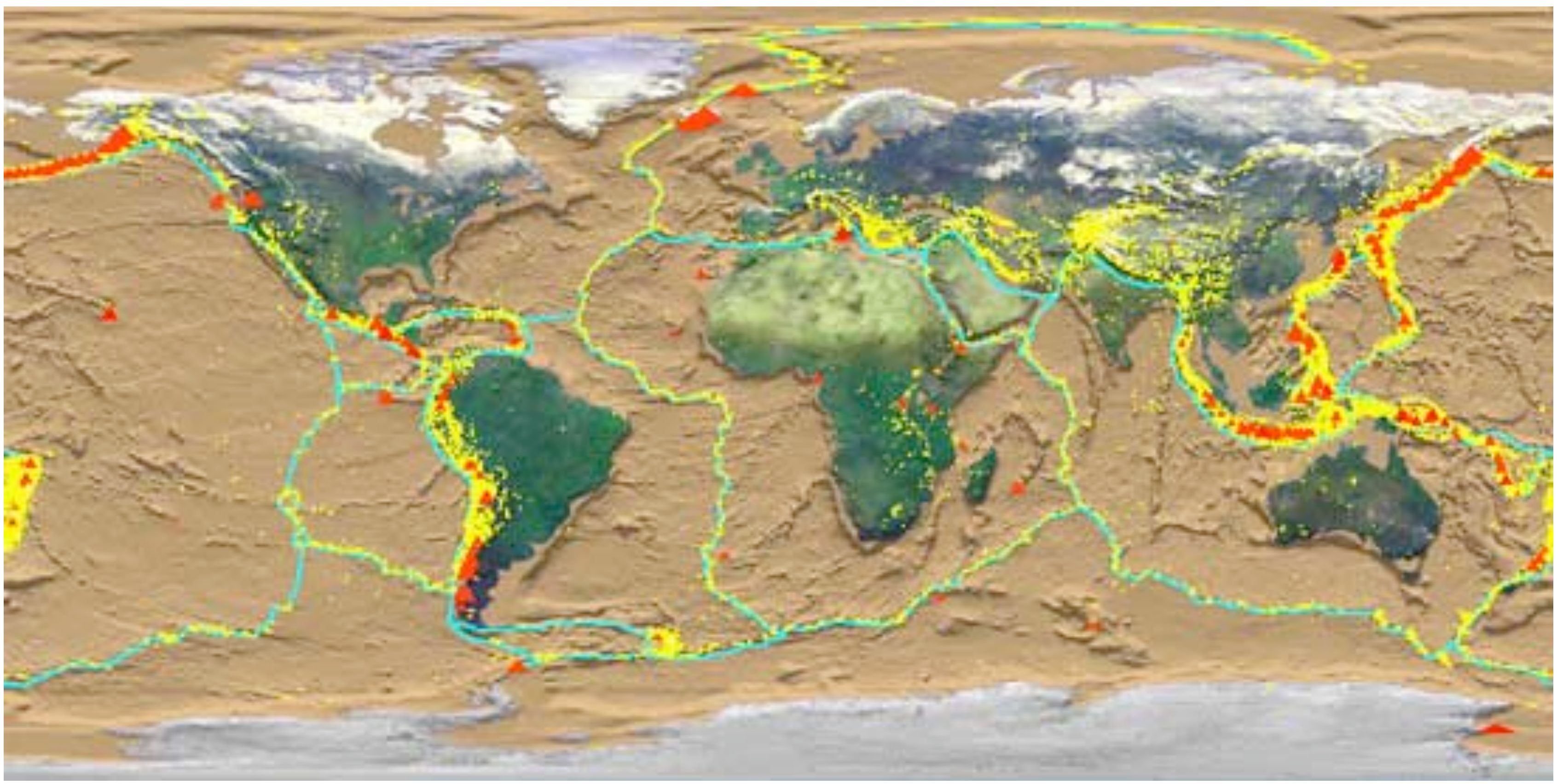
Earth's major topographic features are tectonically controlled.



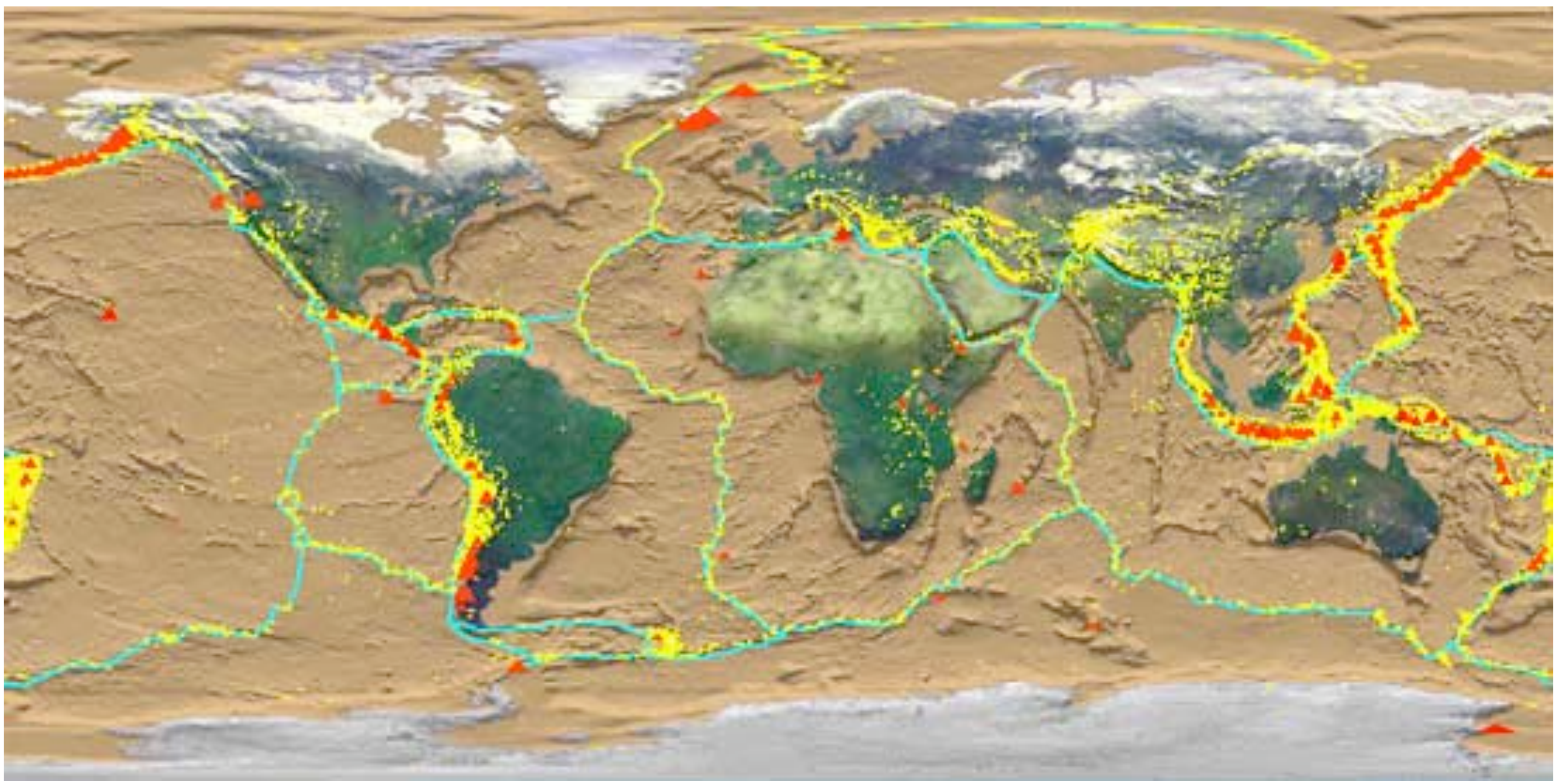
Major mountain ranges are loacted along plate boundaries



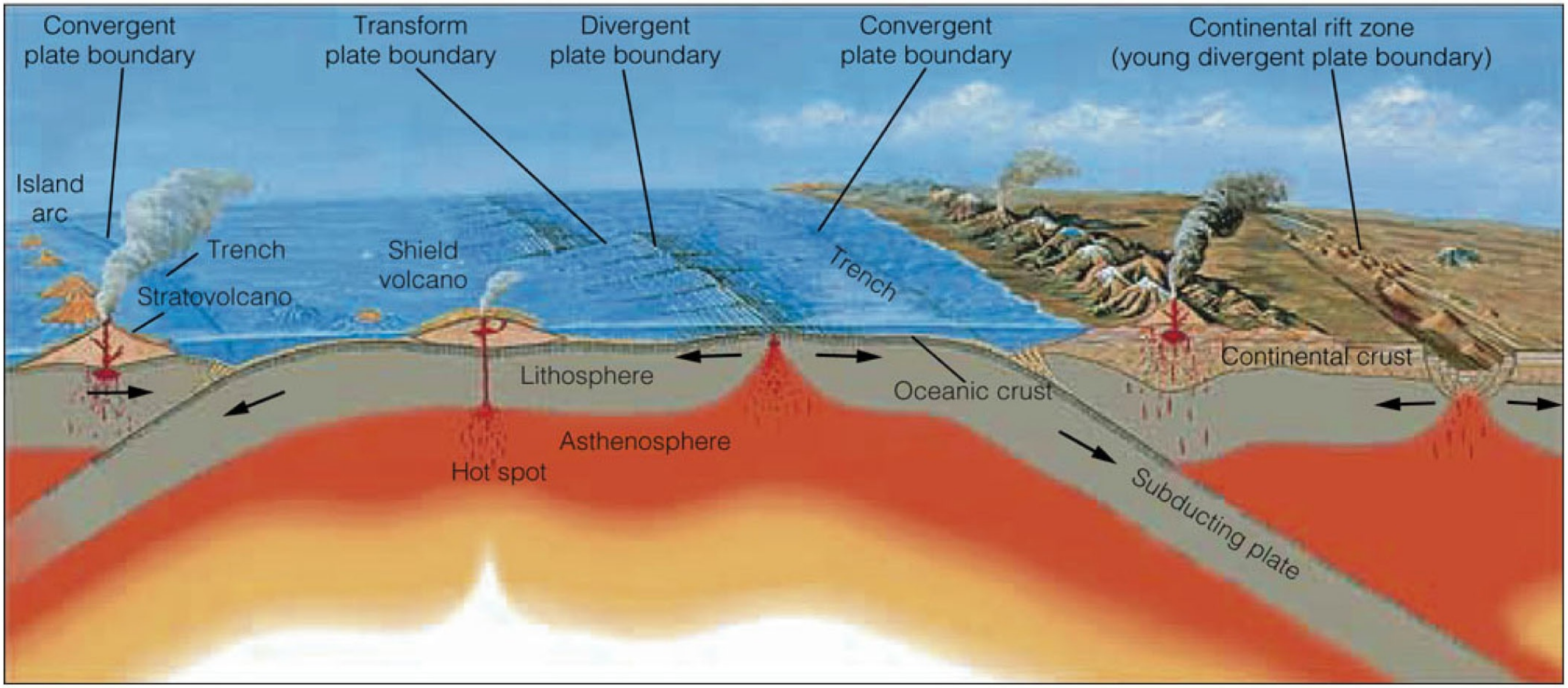
Active margin: The greater relief of the western United States reflects its position along an active margin. Note the distinct areas in which different tectonic boundary conditions give rise to very distinctive topography.



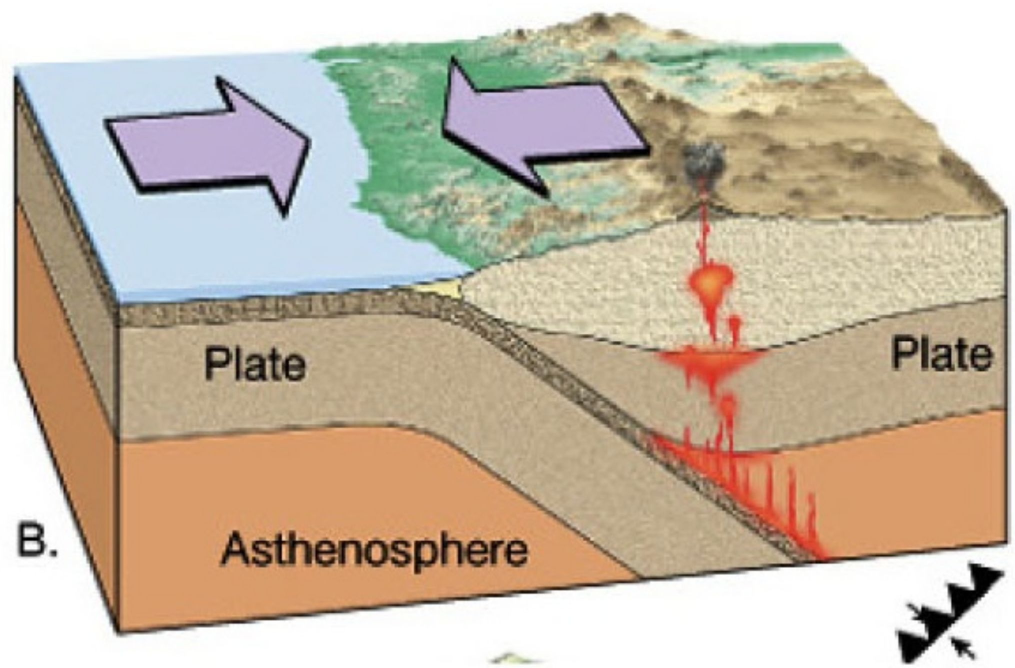
Passive margin: The East Coast of the United States is a passive margin where lack of active uplift and ongoing erosion has reduced the Appalachians to relatively subdued topography.



Relation of Earth's crust to deeper structures

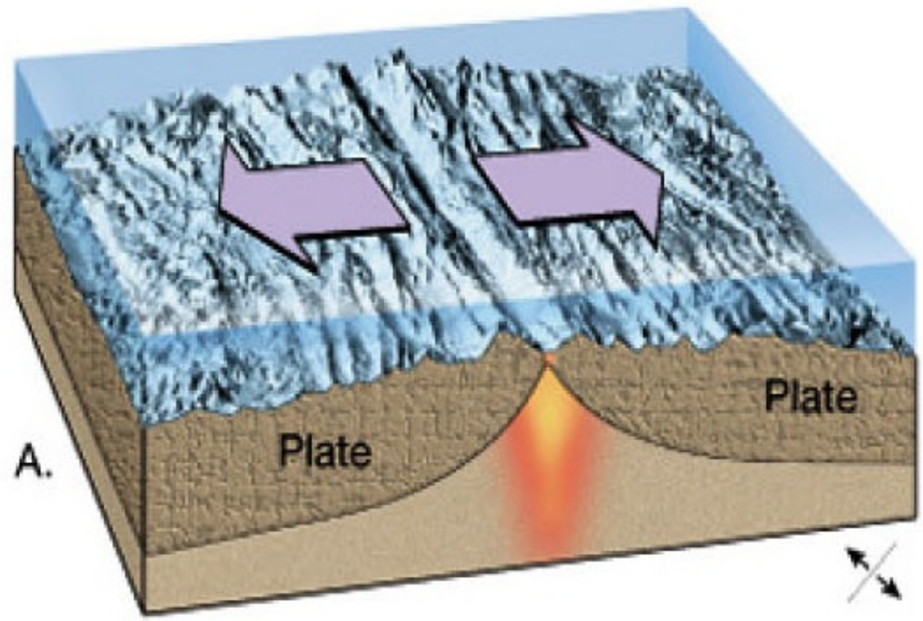


Classification and primary characteristics of plate boundary types



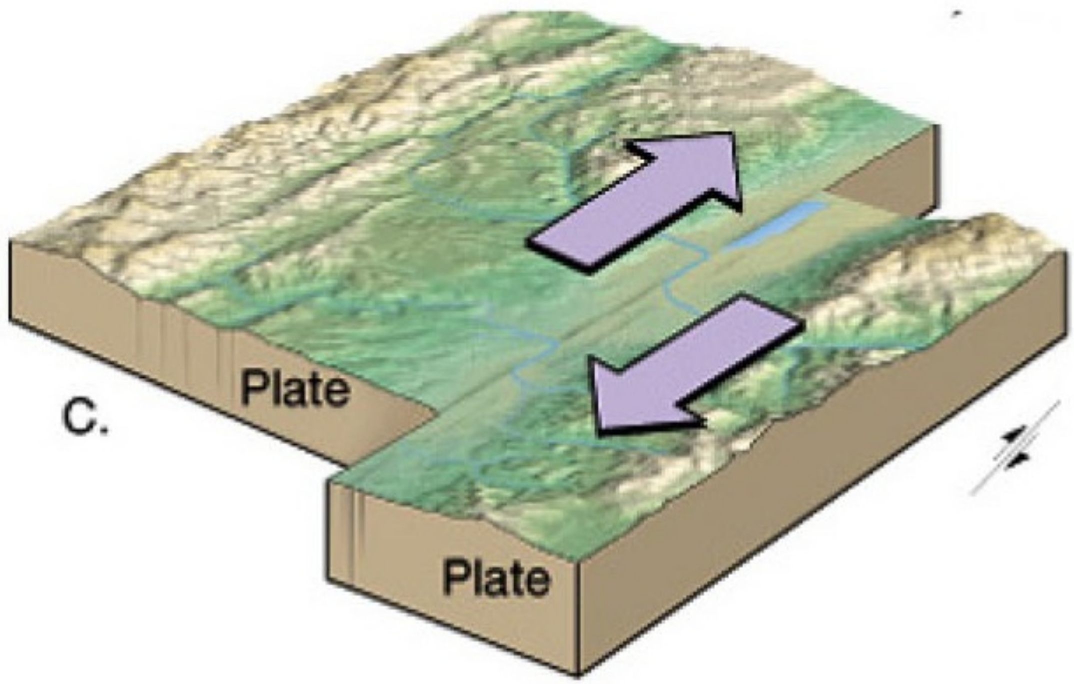
Convergent Boundary

Coastal sedimentary wedge and volcanic arc mountain system
Cascade Range
Himalaya (continent - continent collision)



Divergent Boundary

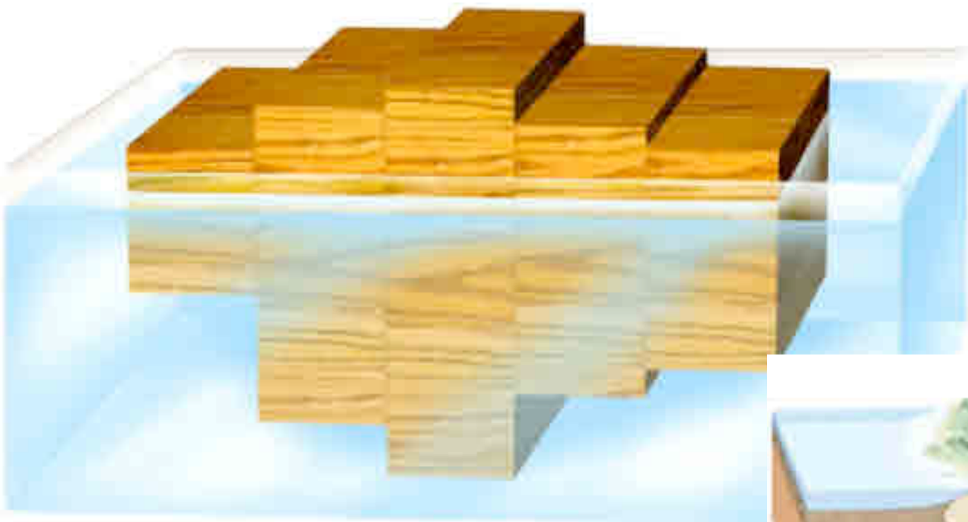
Mid-ocean spreading center or continental rift zone (if on land)
East African Rift Zone, Red Sea



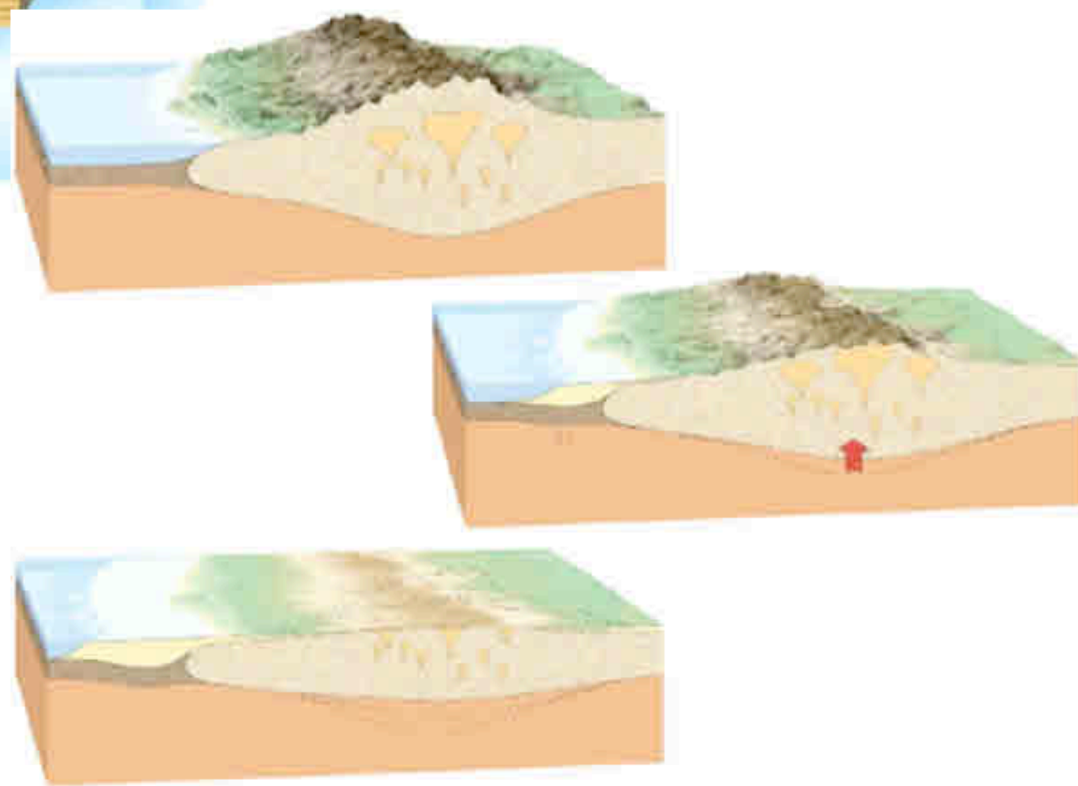
Transform Boundary

Lateral displacement dominates
San Andreas Fault Zone (California)

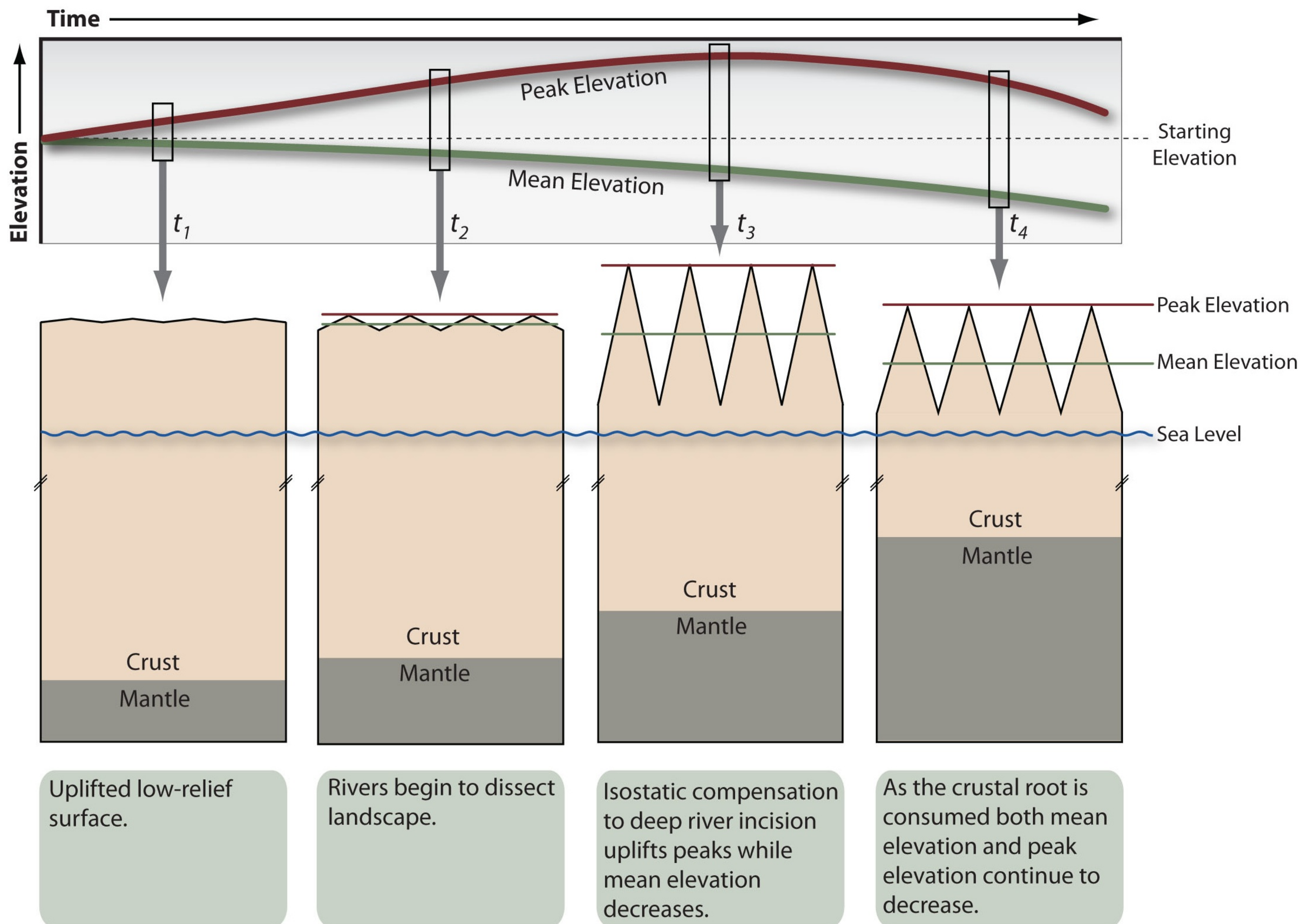
Isostatic Mountains



Continents behave like wooden blocks in water…



Mountains Uplift as they are eroded… Basins depress as they fill…


Time
Elevation
Peak Elevation
Mean Elevation
Starting Elevation
t_1
t_2
t_3
t_4
Peak Elevation
Mean Elevation
Sea Level
Crust
Mantle
Crust
Mantle
Crust
Mantle
Crust
Mantle
Uplifted low-relief surface.
Rivers begin to dissect landscape.
Isostatic compensation to deep river incision uplifts peaks while mean elevation decreases.
As the crustal root is consumed both mean elevation and peak elevation continue to decrease.

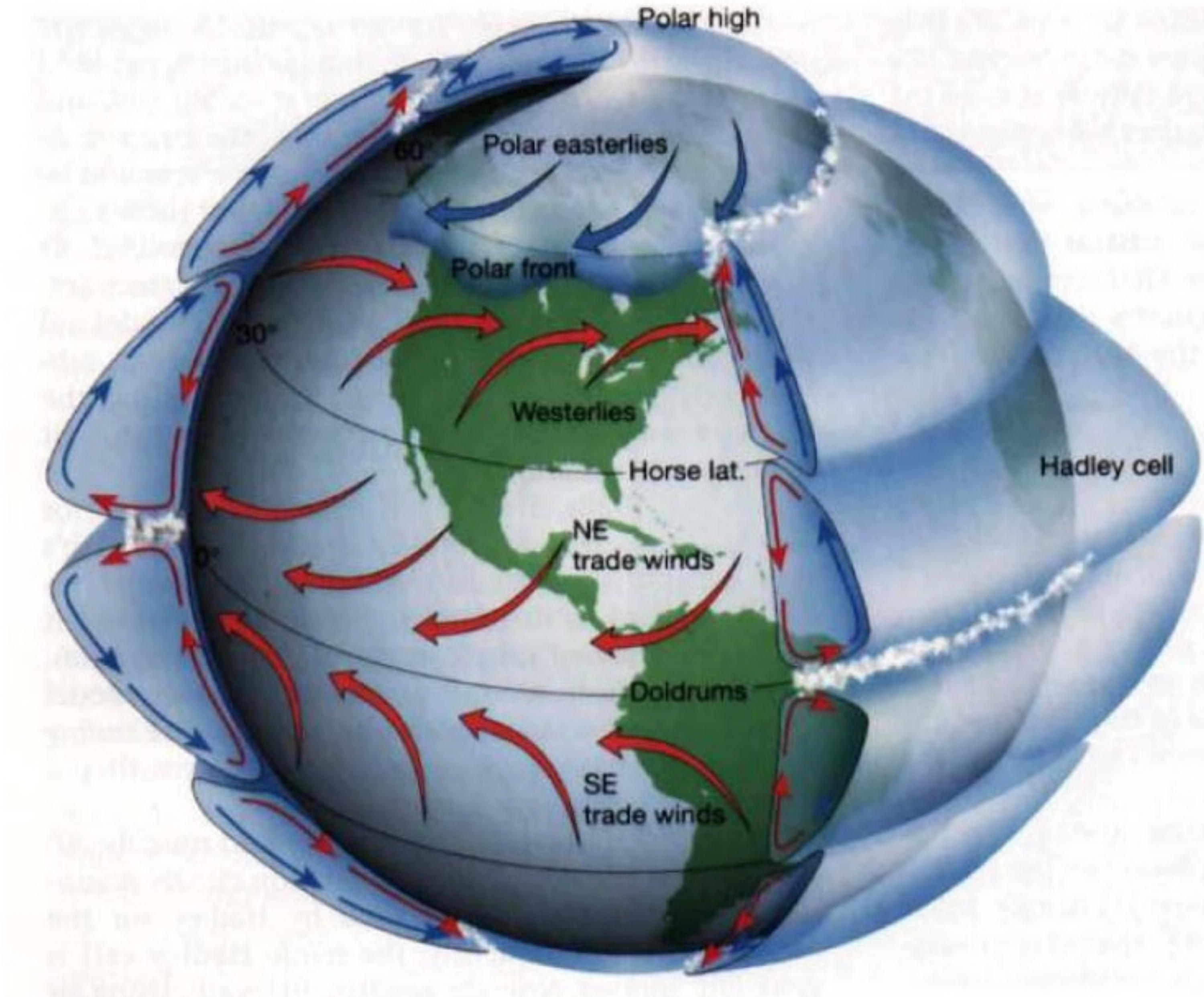
Climate

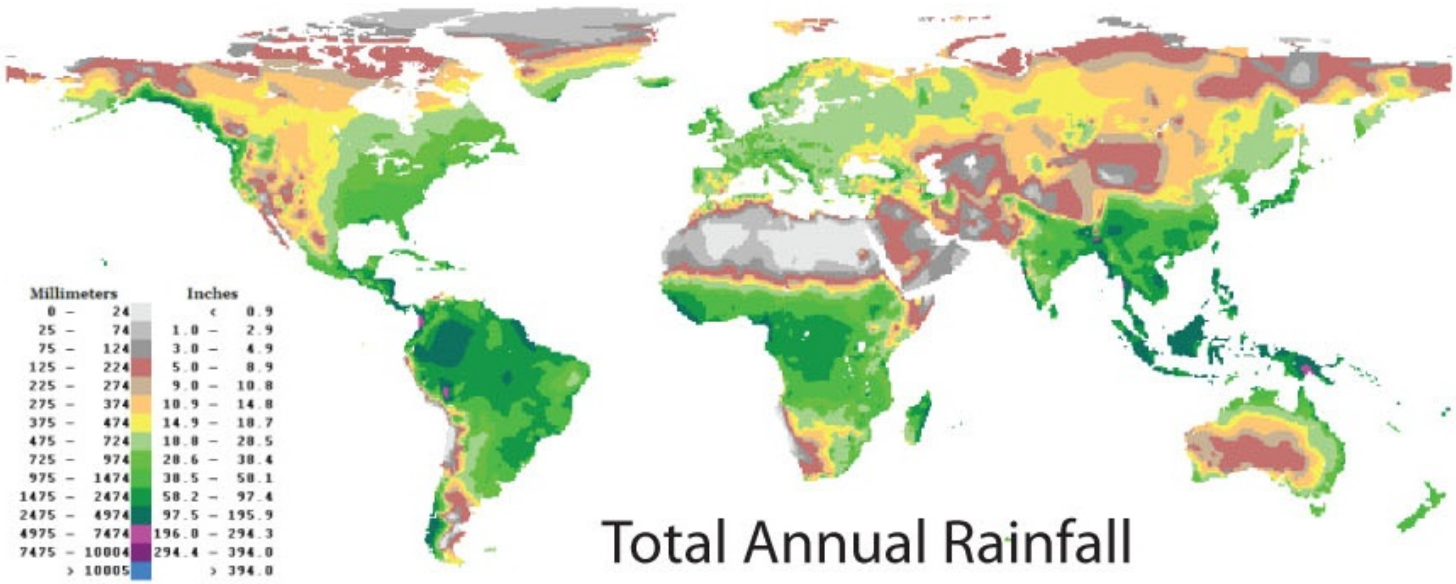
Both spatial patterns in climate and long-term changes in climate can leave distinctive signatures on land form.

Examples of the both fine-scale and larger-scale signature of climate and climate history include:

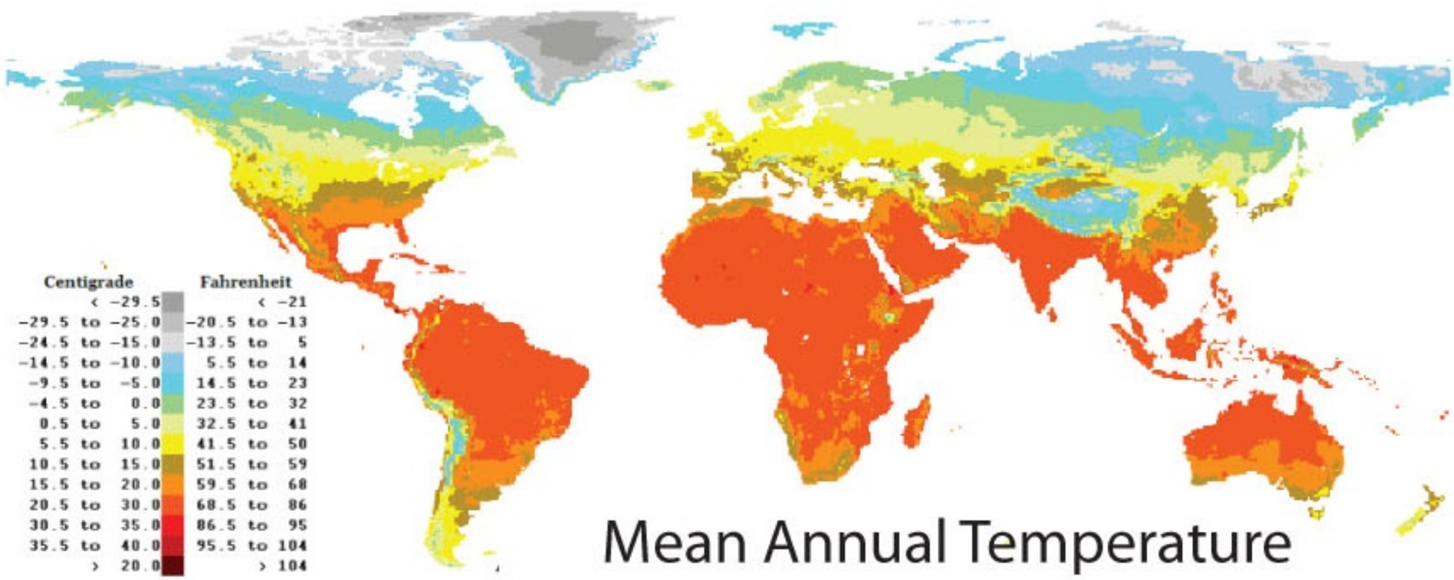
Effect of differences in climate on landforms

Relict topography formed by now inactive processes. The lowlands surrounding the Puget Sound provide perhaps the best local example of relict topography sculpted when over a kilometer of ice stood over our heads.

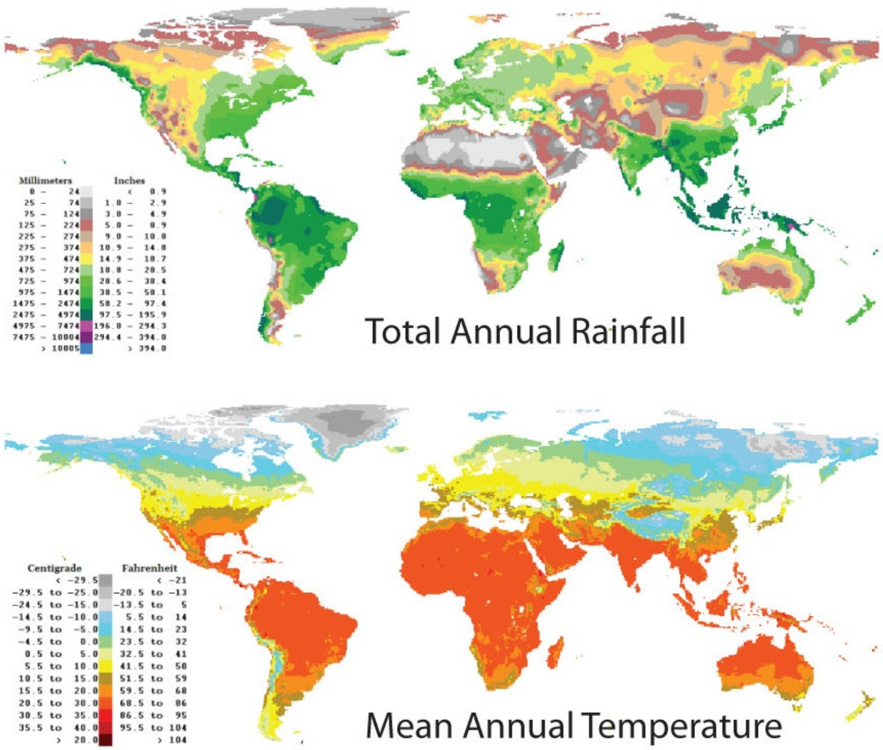

Polar high
60°
Polar easterlies
Polar front
30°
Westerlies
Horse lat.
Hadley cell
0°
NE
trade winds
Doldrums
SE
trade winds



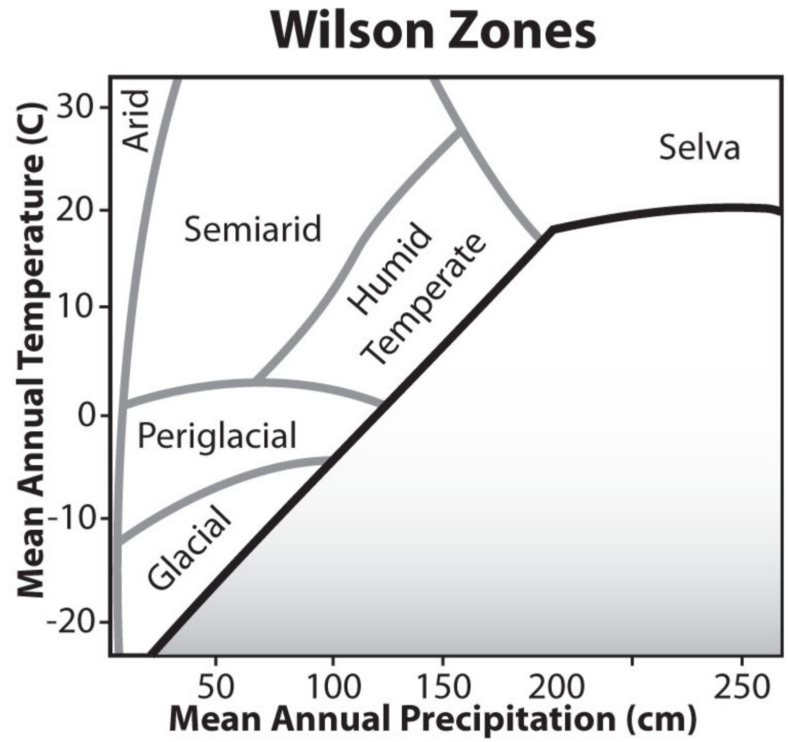
Total Annual Rainfall



Mean Annual Temperature

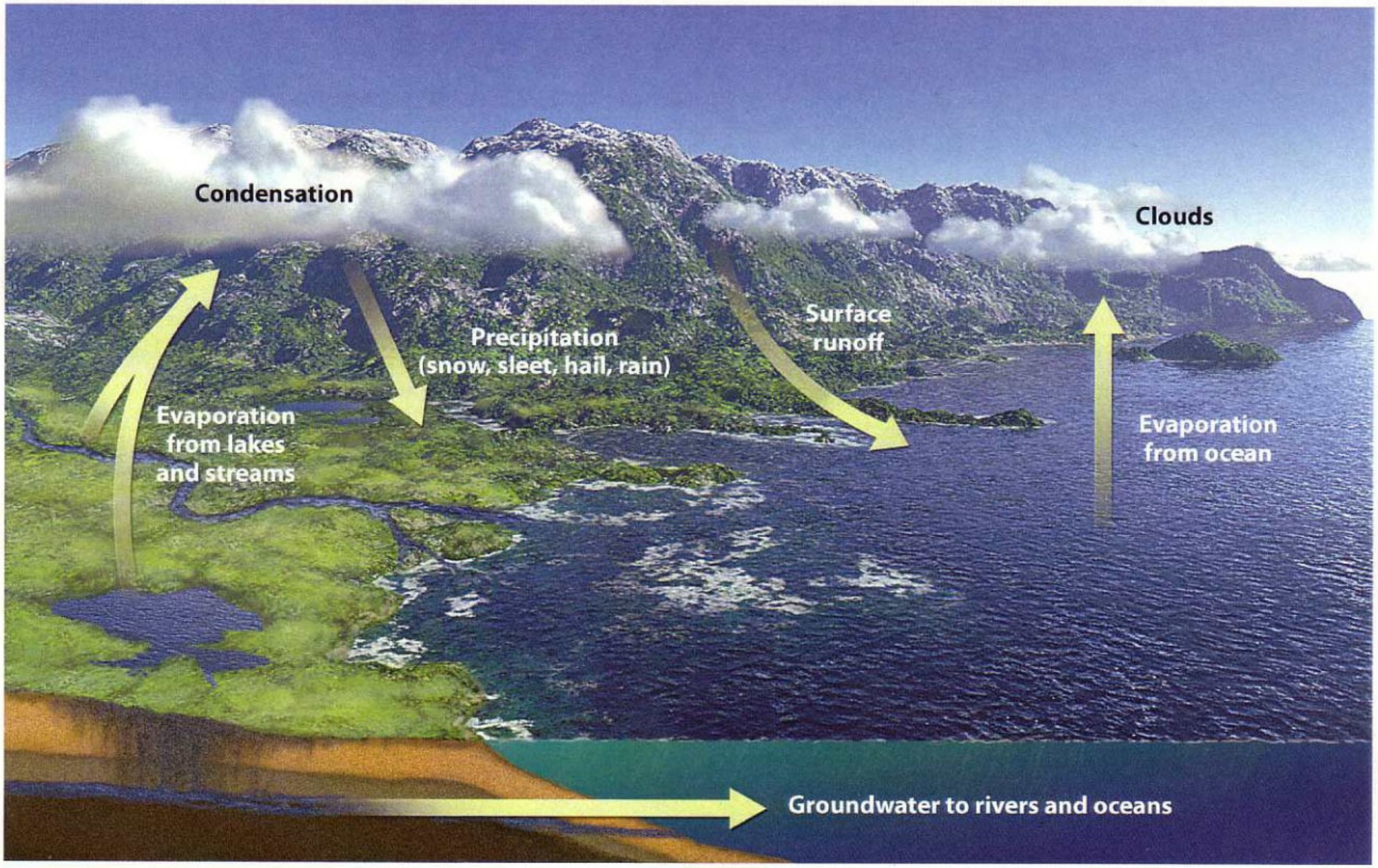


Millimeters
Inches
Total Annual Rainfall
Centigrade
Fahrenheit
Mean Annual Temperature

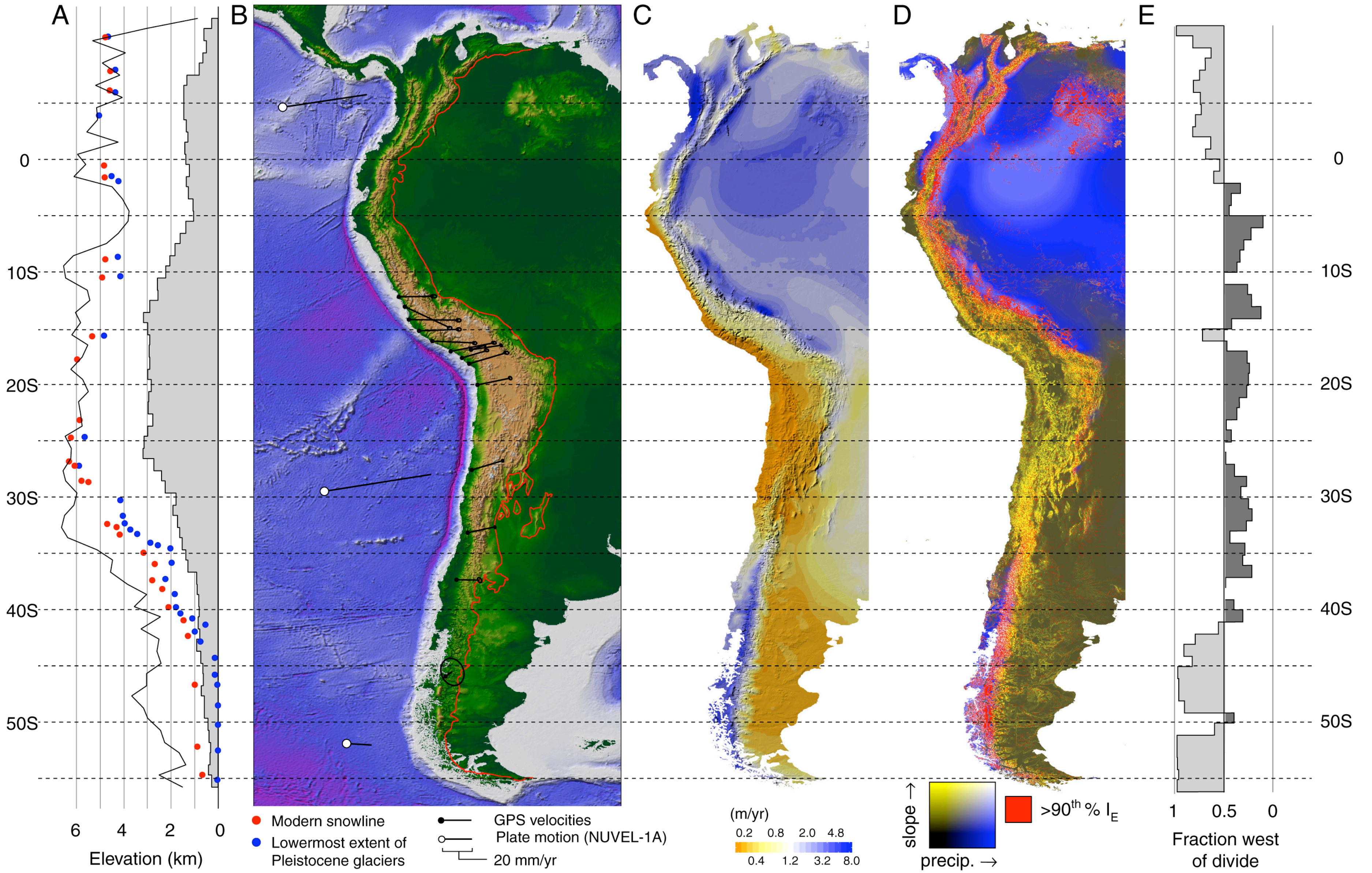


Wilson Zones
Arid
Semiarid
Humid
Temperate
Selva
Periglacial
Glacial
30
20
10
0
-10
-20
50
100
150
200
250
Mean Annual Temperature (C)
Mean Annual Precipitation (cm)

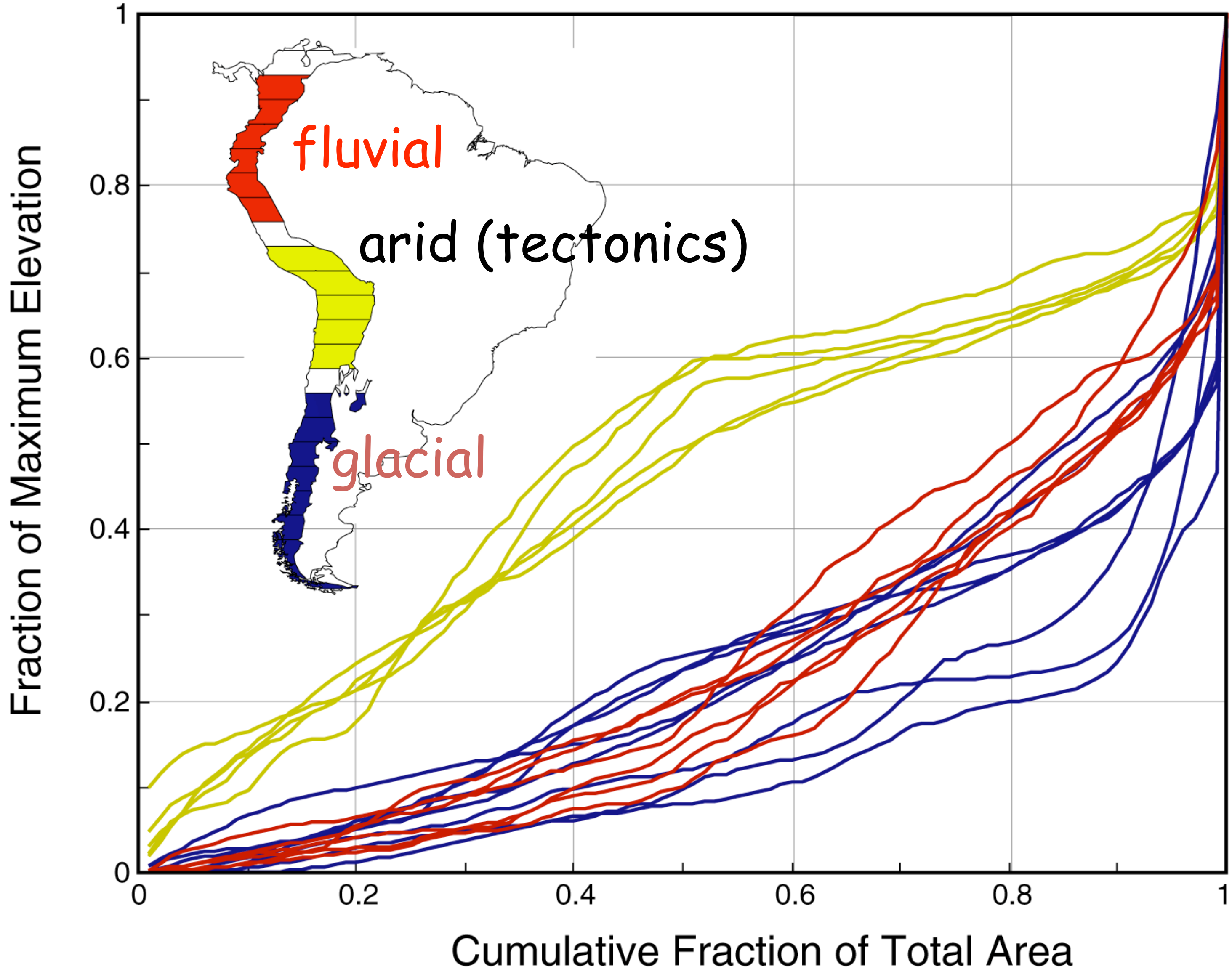
Hydrologic cycle



Climate zonation of South America influences the shape of the Andes



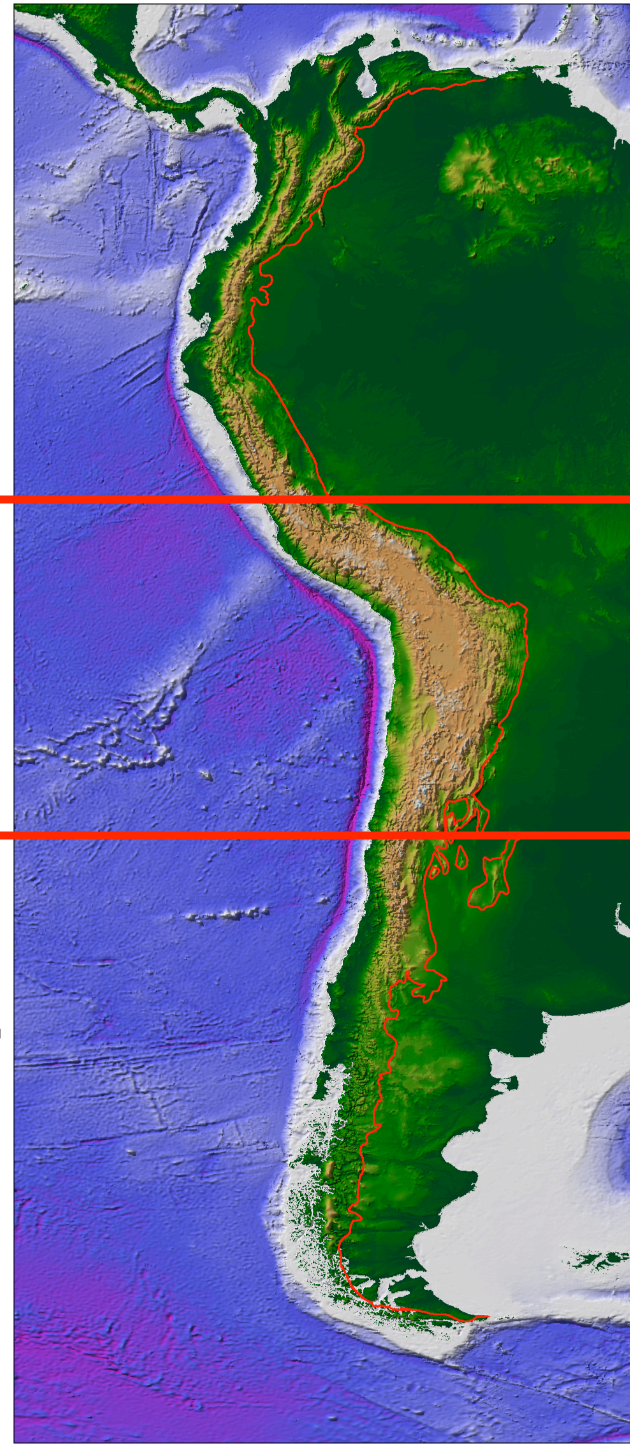
Hypsometry of the Andes



Climate forcing … fluvial

Tectonic forcing … arid

Climate forcing … glacial



Erosion

Erosional processes that remove and redistribute rocks and soil tend to control the fine-scale features of Earth's surface. Different types of processes give rise to hillslopes and valleys with distinctive morphologies (forms).

Primary erosional processes shaping Earth's surface:

<u>Mass Movements (Hillslope Processes)</u>
- deep-seated bedrock failures
- shallow landsliding involving mostly surficial materials
- soil creep and biogenic transport

<u>Streams and Rivers (Fluvial Processes)</u>
- small ephemeral channels
- steep mountain channels
- large floodplain rivers

Glacial and Periglacial Processes

- ice sheets; low-gradient, pot-holed topography
- valley glaciers; U-shaped valleys
- solifluction

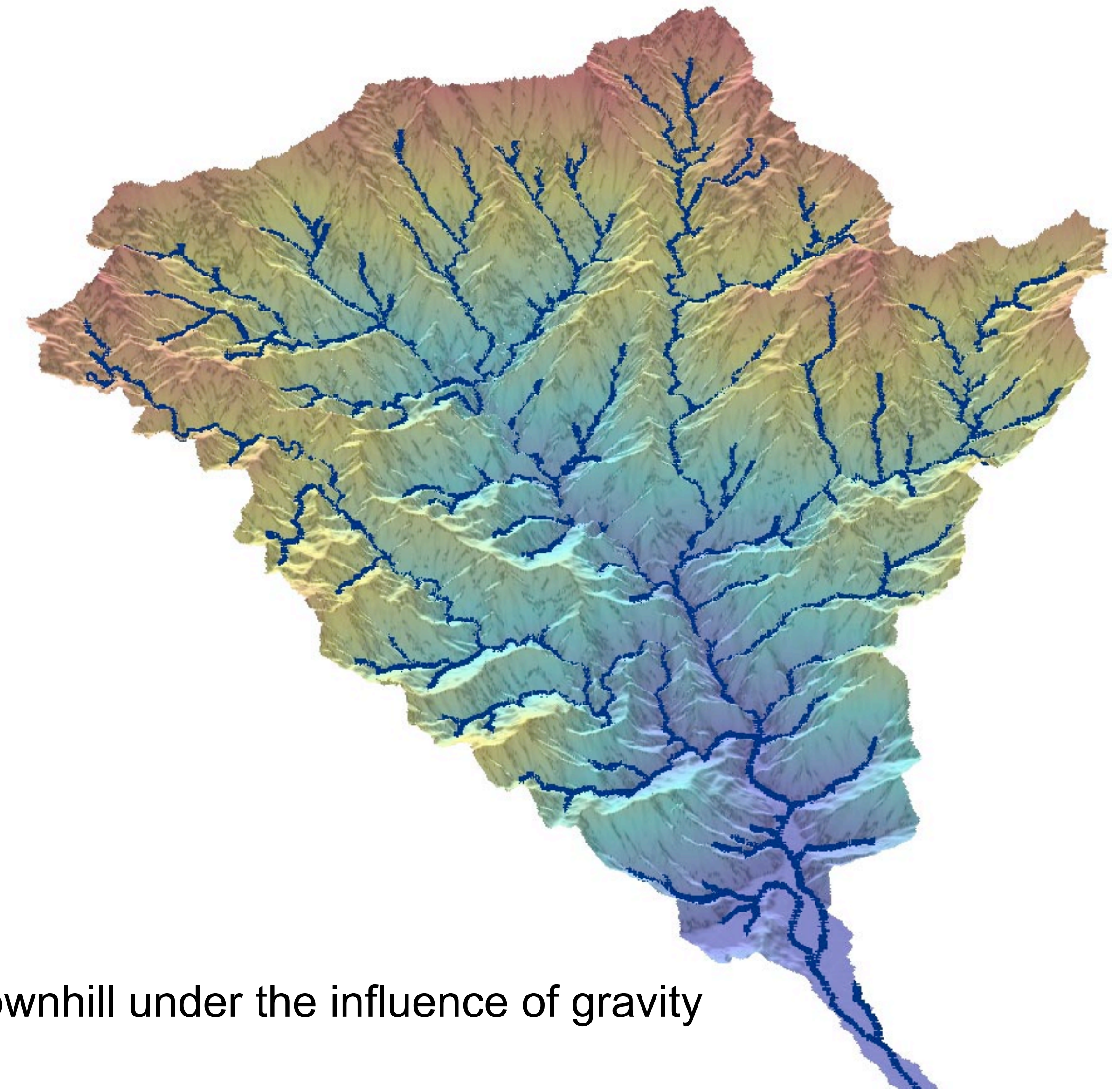
Wind (Aeolian processes)

- sand dunes

Volcanic Processes

- eruption-related erosion and deposition

Drainage basins



Material moves downhill under the influence of gravity

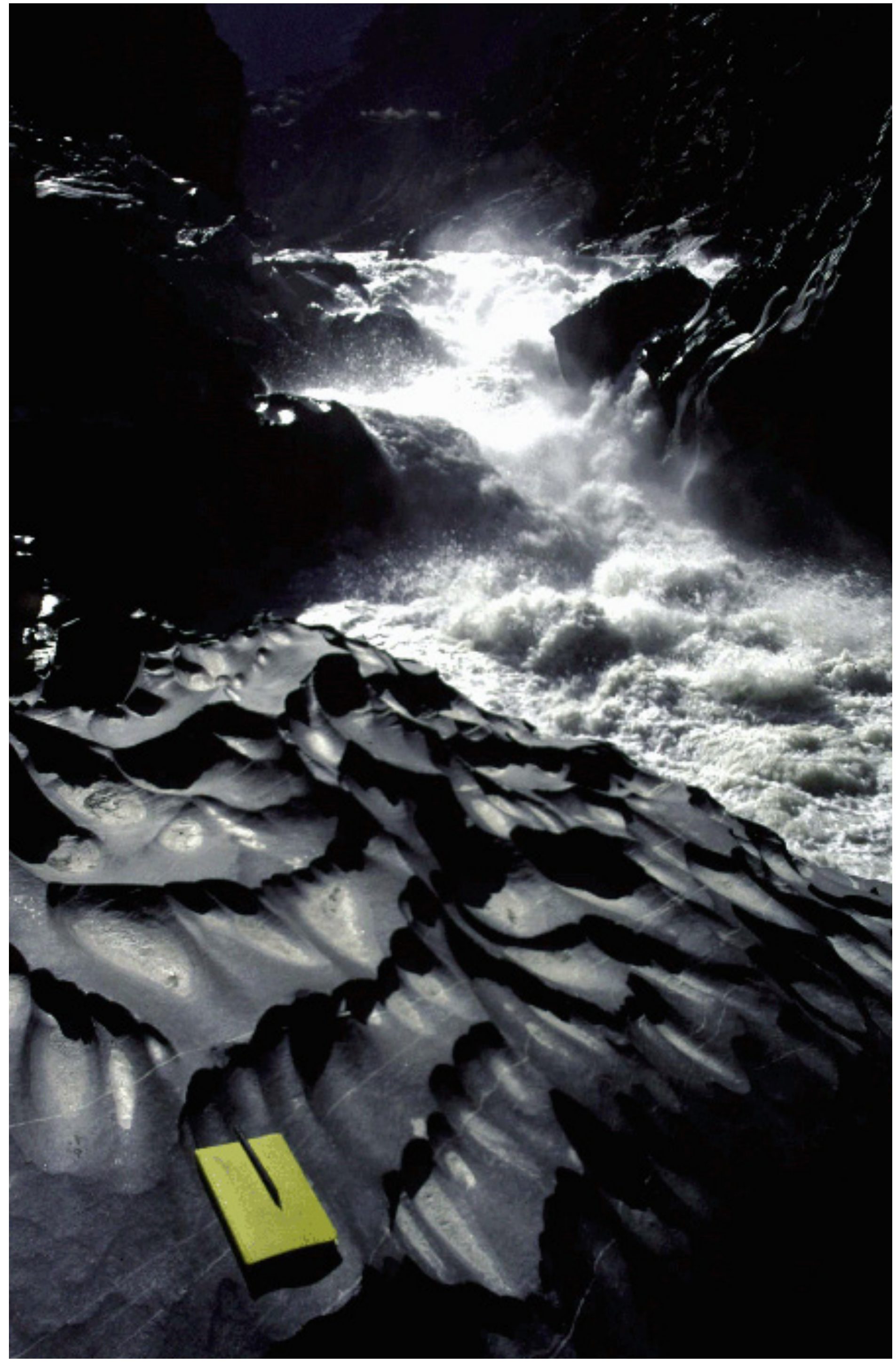
Mountain systems

Hillslopes closely coupled with rivers

Rivers have high transport capacity and little sediment storage

Mountain systems

Rivers actively cut into bedrock, creating local relief



Mountain rivers carry material to lowlands…

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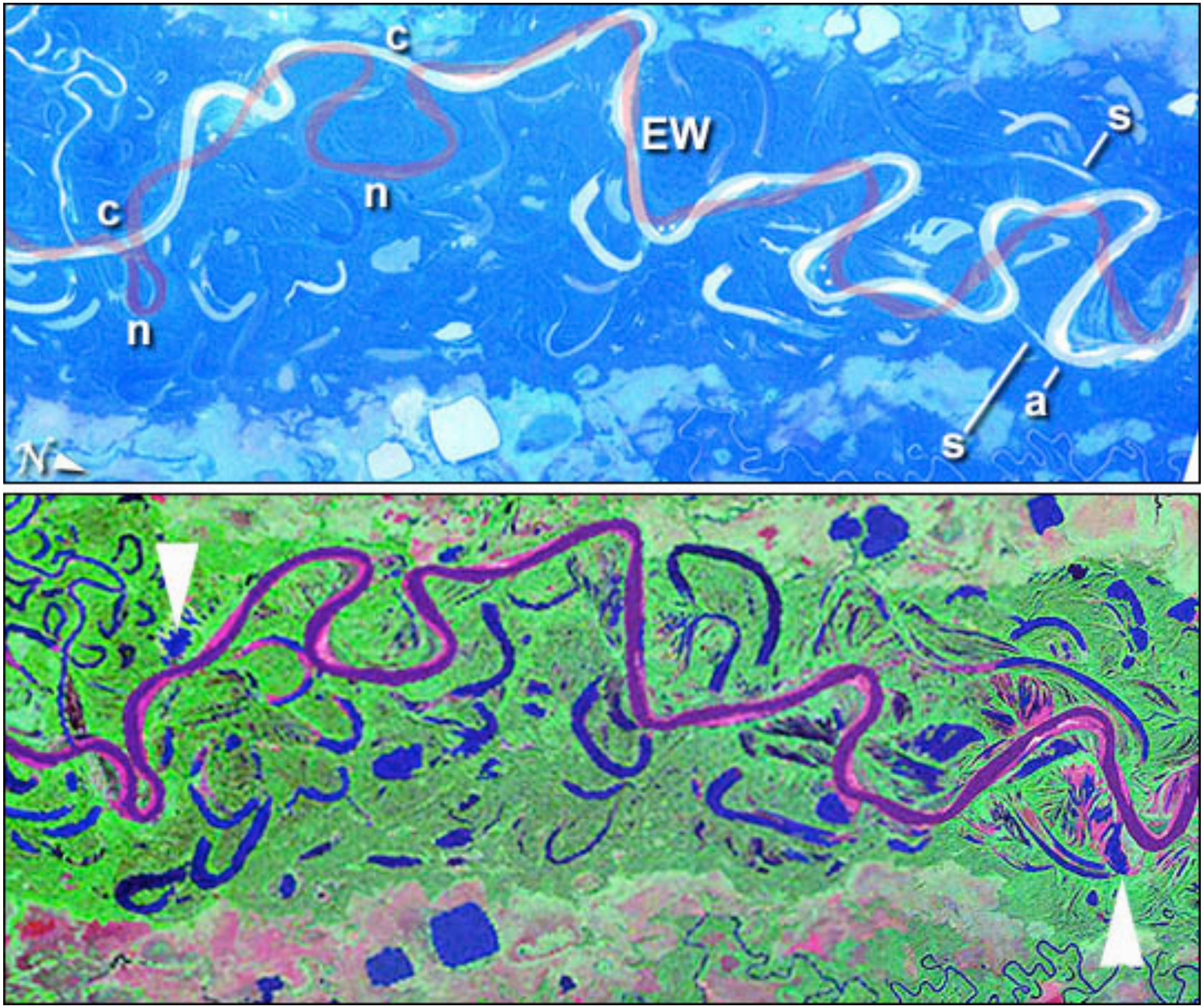
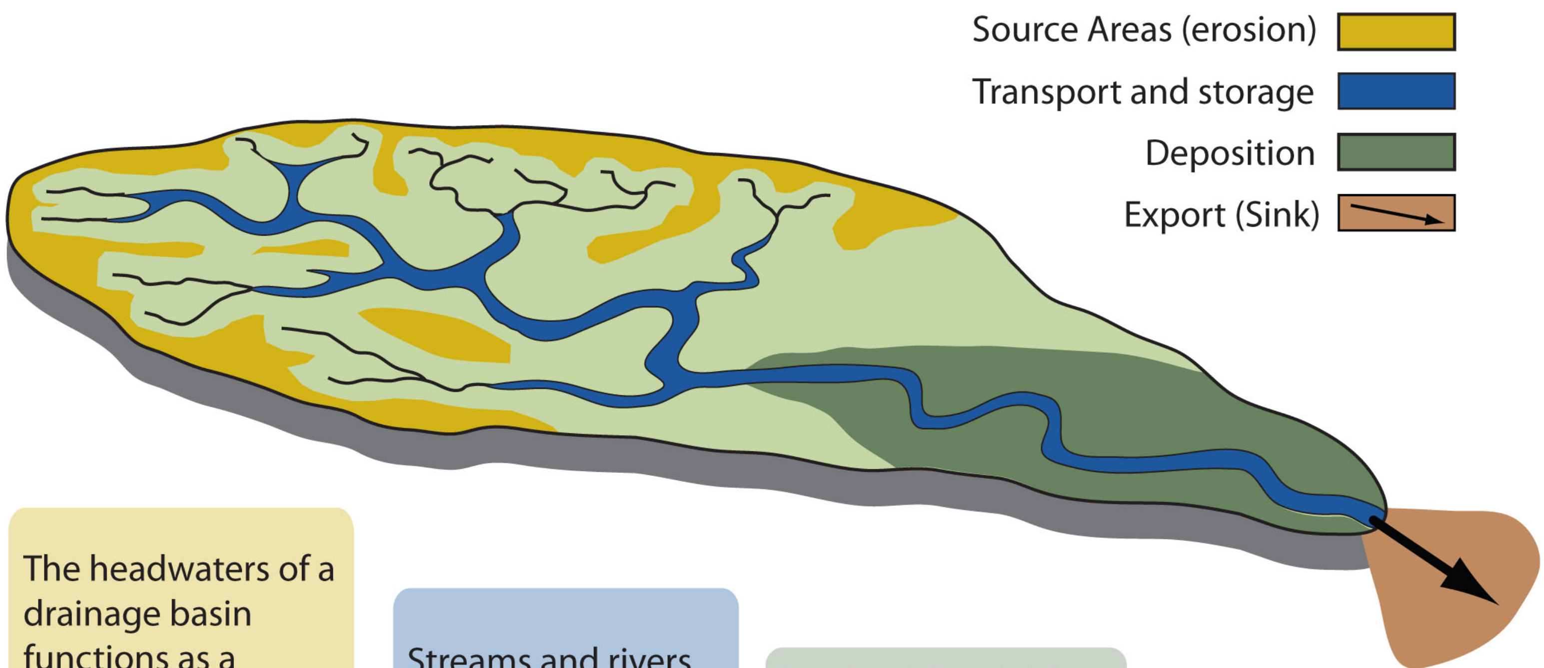
Lowland rivers build depositional floodplains and carry material to the coast…



drainage basin turns out to be quite difficult, and drafting in 3D in illustrator is rather awkward, so we could use all the help we can get.

Drainage basins are systems…



The headwaters of a drainage basin functions as a sediment source where weathering breaks down rocks and erosional processes deliver sediments to stream and rivers.

Streams and rivers both transport material and create storage elements through the inter-change of sediment with floodplains.

Lowland floodplains and estuarine areas function as long-term depositional areas where sediment inputs may exceed sediment outputs.

Sediment making it through lowland and estuarine areas to reach the coast is exported to the marine environment, which serves as a long term sediment sink

Ecological Importance of Geomorphological Processes

The interaction of Earth Surface processes create the physical environment for ecological systems, which provides habitat to organisms including humans.

Historical Perspective

Civilizations arose in the floodplains of the Tigris and Euphrates Rivers and the valley of the Nile due to the fertile soils replenished by annual flooding.

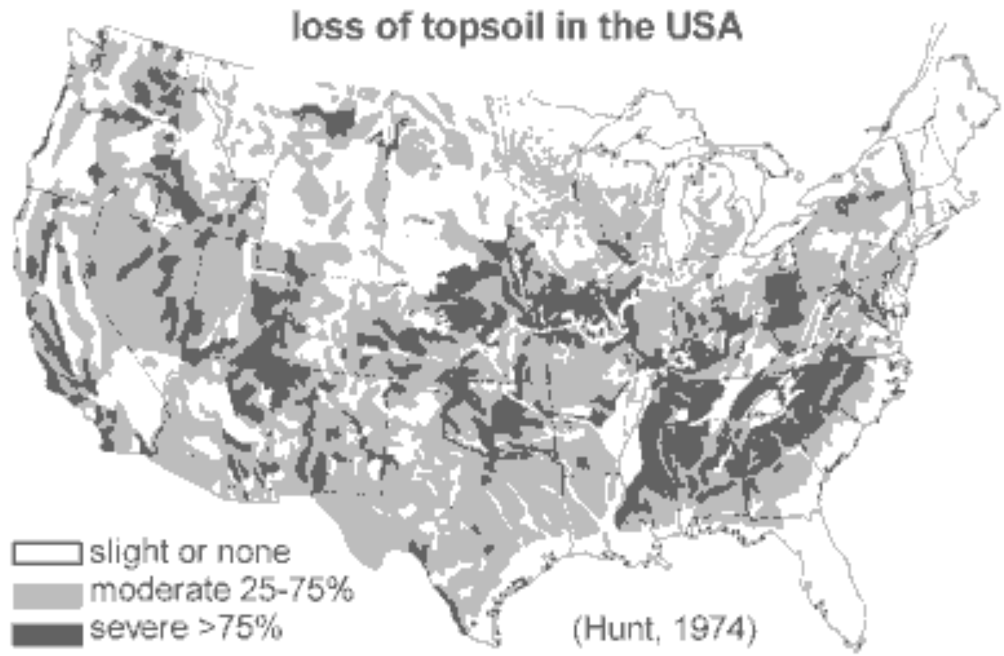
Plato first recognized the effects of human actions on soil erosion and the consequent negative impacts on economic livelihood in classical Greece.

Centuries of intensive soil erosion have impoverished much of the Mediterranean region, where ancient ports are now kilometers inland.

Contemporary Perspective

The "quiet crisis" of soil erosion is still a huge problem in the modern world, as millions of tonnes of topsoil are still lost every year in the U.S. alone.

An excellent regional example is the accelerated erosion from landsliding resulting from historic forest clearing and road building in the Pacific Northwest.


loss of topsoil in the USA
slight or none
moderate 25-75%
severe >75%
(Hunt, 1974)

Key questions about geomorphological systems

- What controls the dominant geomorpholgical processes in a landscape (e.g., fluvial, glacial, coastal)?

- How do all the pieces fit together in shaping landscapes?

- How do the spatial arrangement of landscape elements influence landscape dynamics?

Role of history

Earth is a planet that, like all the others, has a unique history that gives rise to a wide variety of land forms.

Earth is, in effect, a single, long-running geomorphological experiment.

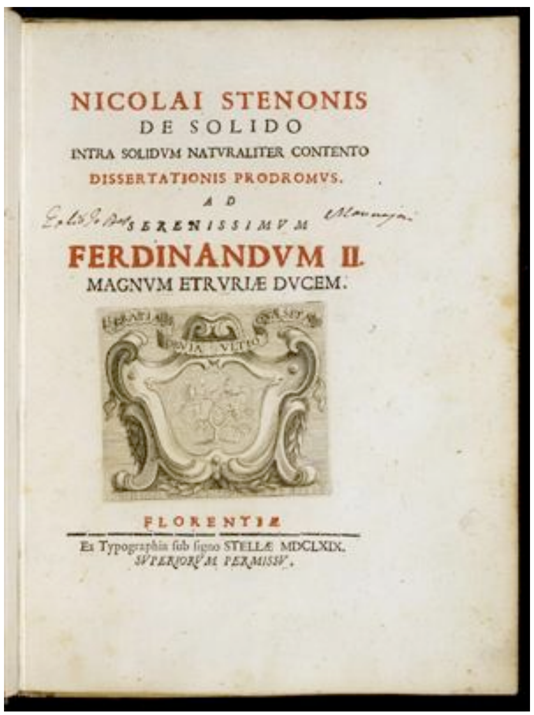
A 10-Minute History of Geomorphology

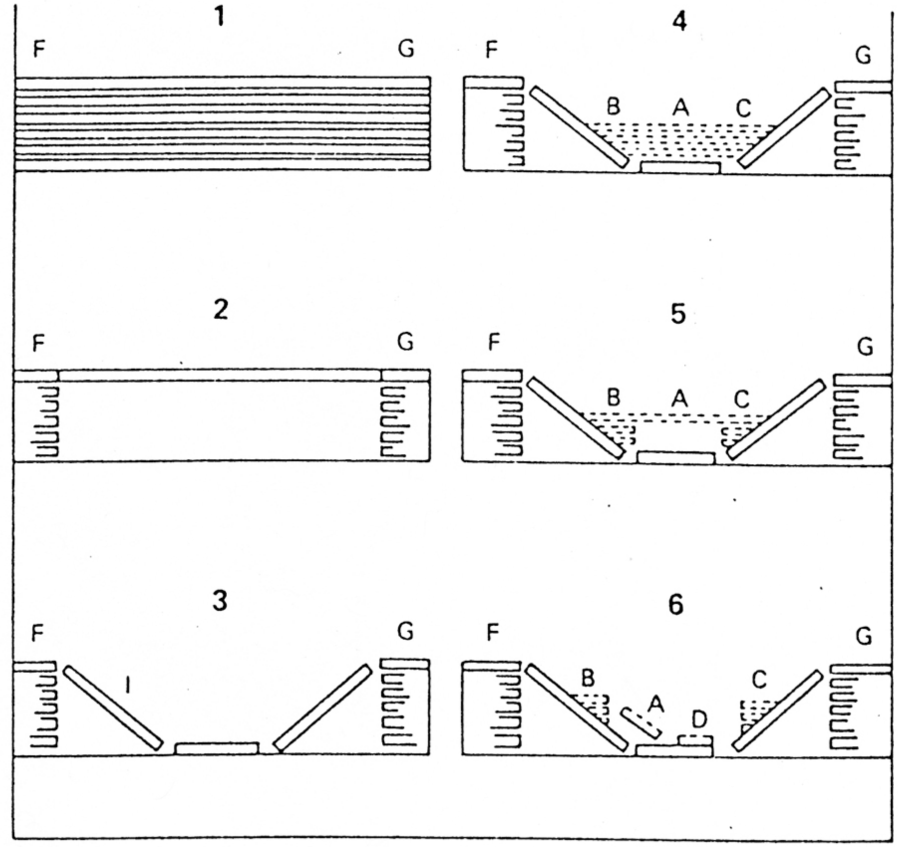
Leonardo da Vinci (1452-1519) - Leonardo's works on topographic evolution and his invention of the contour map are not widely recognized because he did not publish (he never would have received tenure).

Water is the driver of Nature.
- Leonardo da Vinci

A 10-Minute History of Geomorphology

Steno (1669) recognized the need to explain the history (and hence evolution) of land forms.





(1) Precipitation of sedimentary rocks into a universal ocean.

(2) Earth's pristine surface; development of subterranean caverns by sapping.

(3) Collapse of undermined continents, valleys drowned by the sea = Flood.

(4) New sedimentary rocks form in valleys, including fossils.

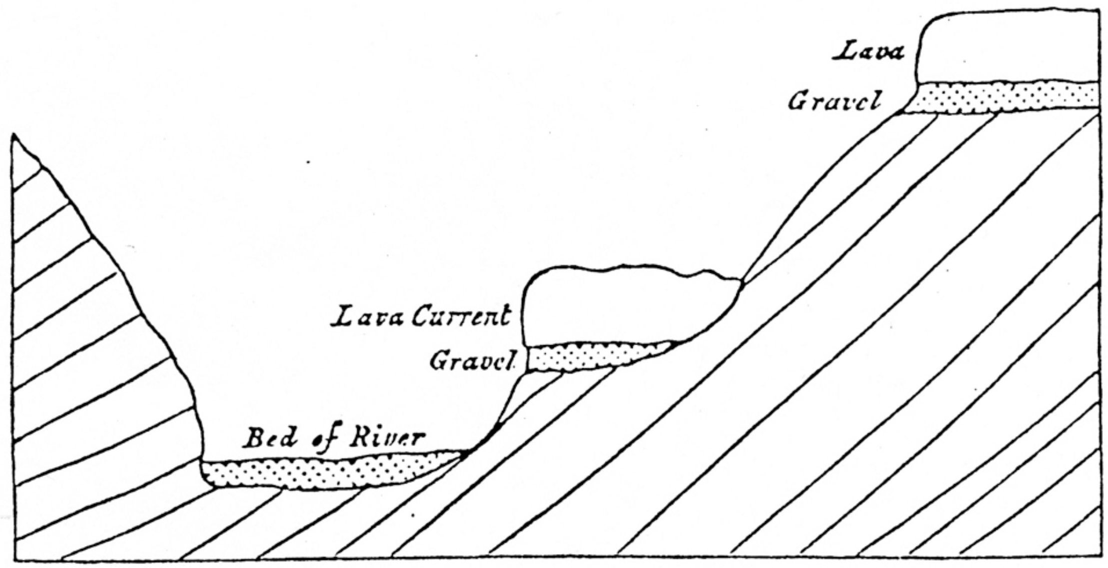
(5) New rocks emerge at the end of the Flood, undermining as in (2).

(6) More collapse to create the present topography.

Valley Formation

Factors controlling the carving of valleys were a key issue in the development of geology as a science.

In the 17th Century it was widely assumed in Europe that the Flood was responsible for topography.



Lavas of Auvergne resting on alluviums of different ages.

Charles Lyell (1833) documented repeated phases of valley cutting, gravel deposition, and burial by lava flows, which demonstrated the need to invoke multiple deluges to account for valley formation.

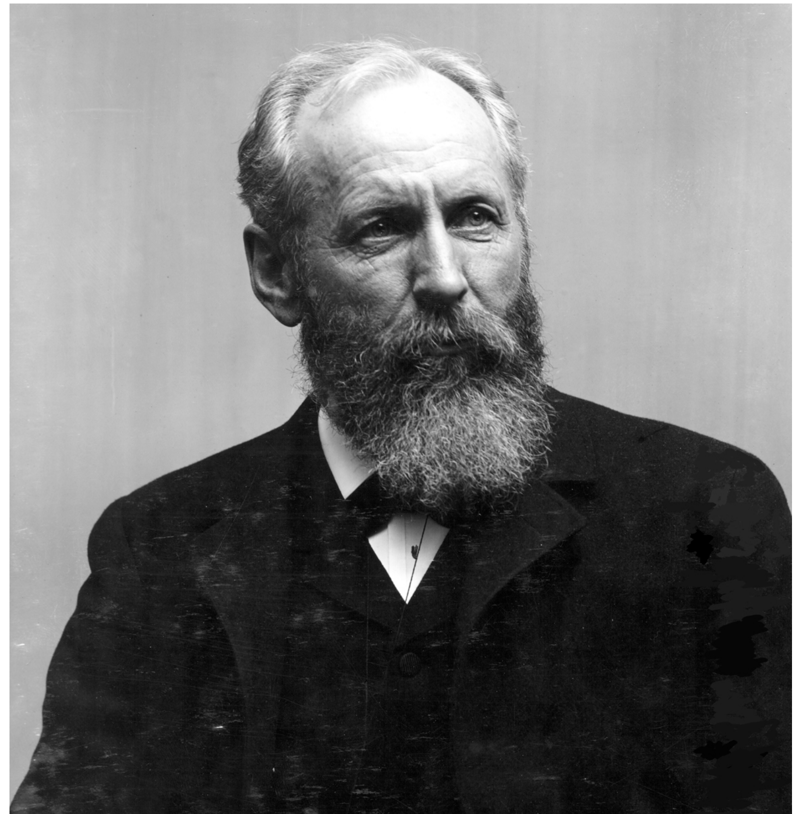
In the 1830's Louis Agassiz began reporting field evidence that suggested a role of glacial processes in carving landscapes. This glacial theory was hotly debated until it was widely accepted by the 1860's.

Rocks polished and striated by a glacier, from Louis Agassiz, *Etudes sur les glaciers*, 1840.

Surveys of the West

The topographic surveys commissioned to inventory the resource potential of the expanding American frontier proved a boon for understanding geological controls on landforms due to the excellent exposures in the arid west.

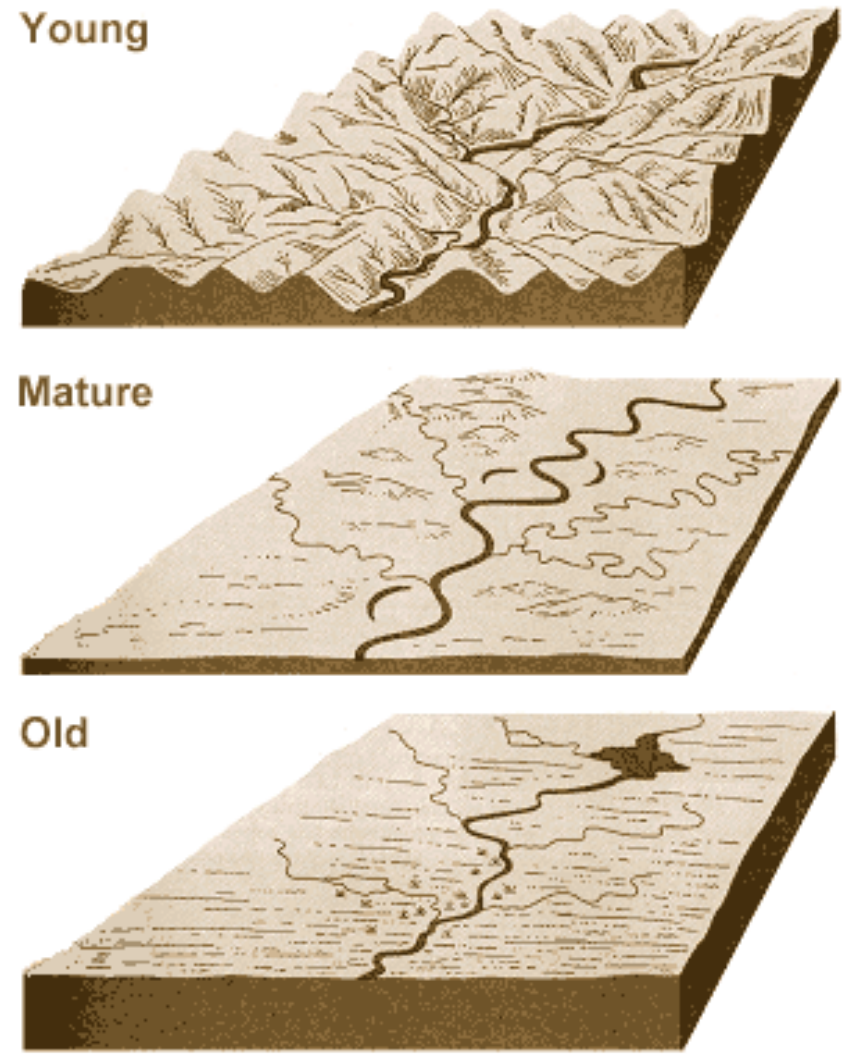
The US Government surveys of 1870's and 1880's produced the geomorphological studies of Powell, Gilbert, and Russell, which gave birth of process geomorphology.



William Morris Davis

At the close of the 19th Century, Davis proposed a broad model of topographic development in which he classified landscapes as youthful, mature, or old based on their general appearance.

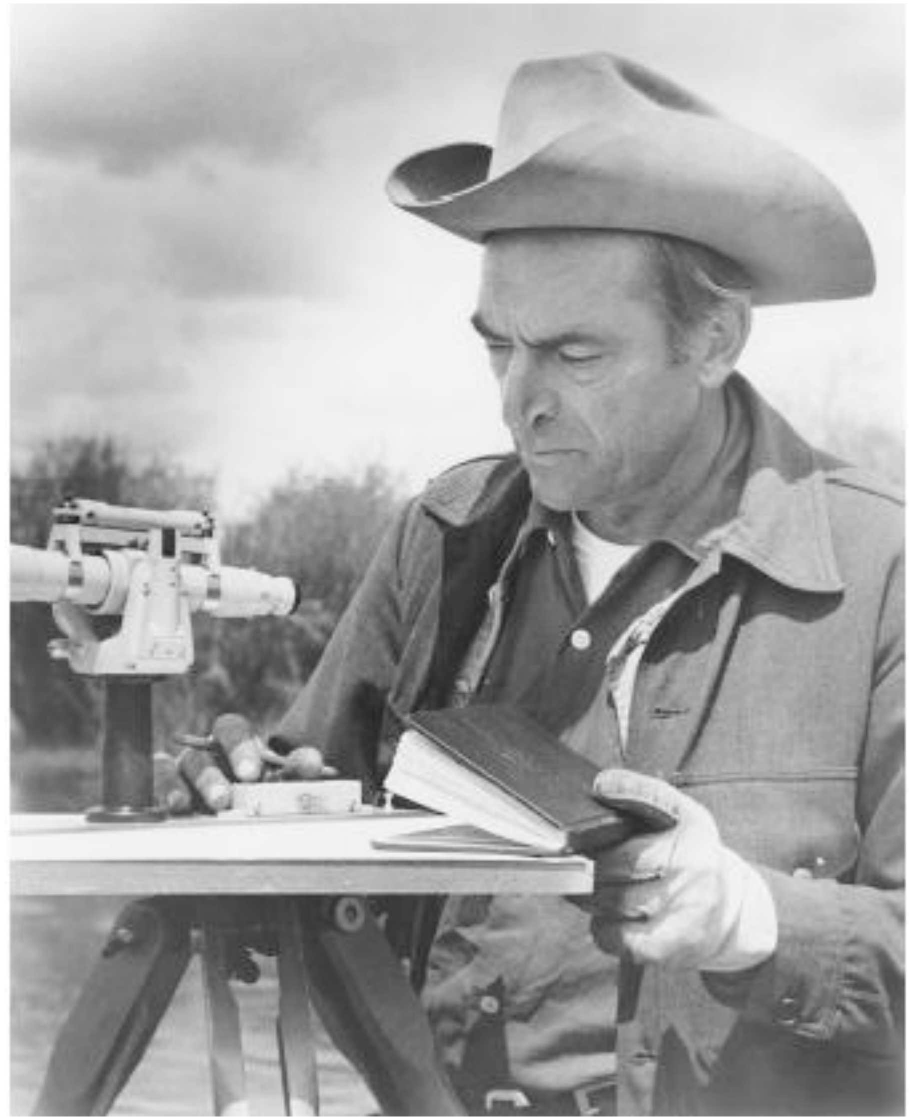
Davis' thinking focused on qualitative interpretation of landscape history from broad aspects of land form and was very influential in the early 20th Century.



Luna Leopold and the U.S.G.S.

In the 1950's a group of U.S. Geological Survey researchers led by Luna Leopold ushered in modern process geomorphology with an aggressive campaign to measure rates of geomorphological processes and explain the physics underlying these processes.

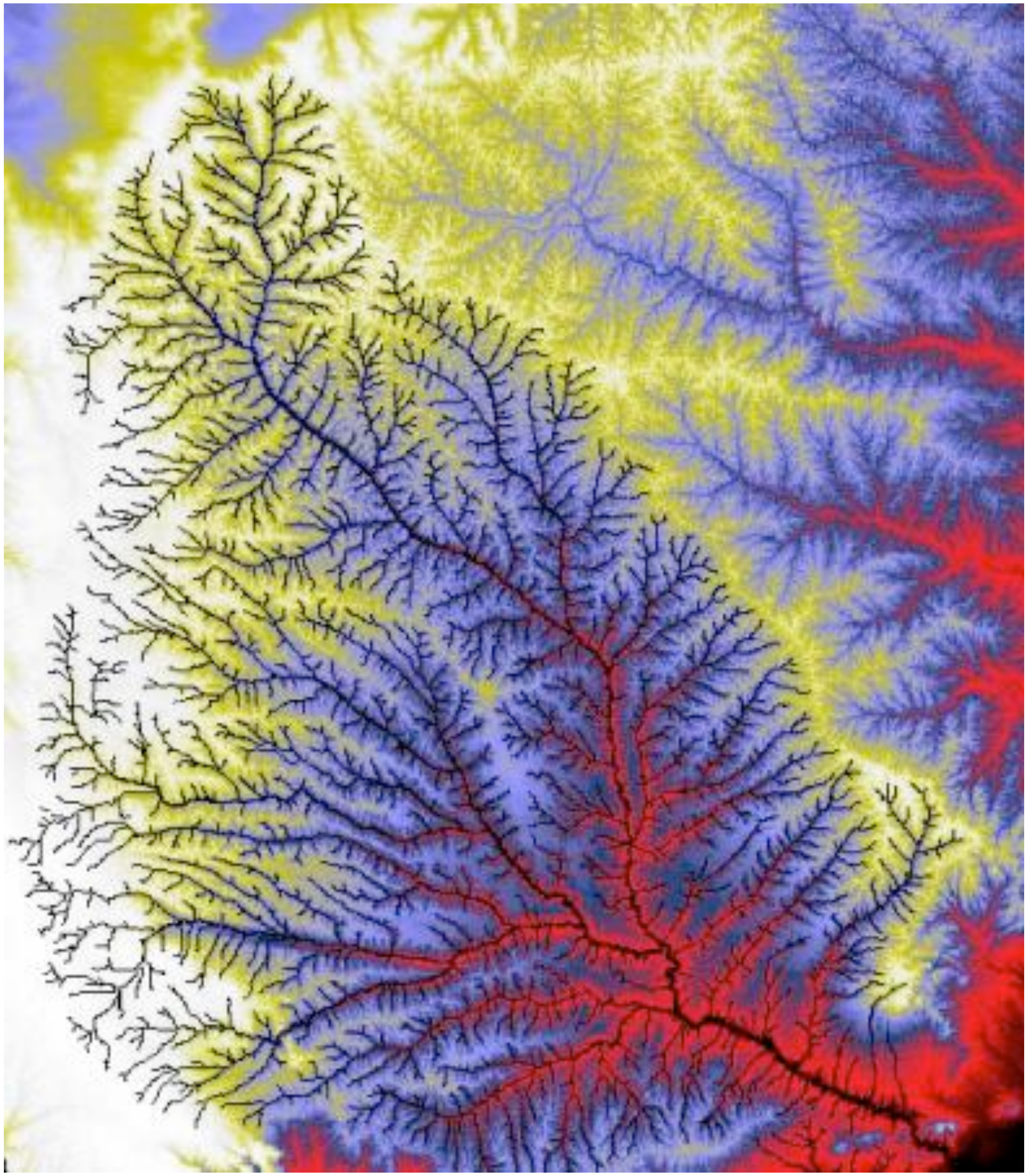
Leopold's approach involved coupling field observations and measurements with theoretical models to explain geomorphological processes.



Digital Elevation Models

The advent of widely available digital models of topography and high-speed computers allows us to image, analyze, and model large landscapes.

Our view of landscapes in the past 20 years has shifted from one of limited analysis of topographic contours, usually focusing on the profiles of individual hillslopes and rivers to fully three-dimensional investigations of entire landscapes.



Evolution of Geomorphic Thought

- Observation
  – Herodotus (450 BC) to Leonardo to present
- Description
  – Steno, Playfair (Hutton) – 1600’s-1700s
- Explanation
  – Agassiz (1807-1873) – glacial
  – Powell (1834-1902) – fluvial/structure
  – Gilbert (1843-1918) – everything!
- Correlation
  – Davis (1850-1934) – fluvial+
  – A. & W. Penck (1900-1950) structure
- Quantification (post-WWII)
  – Leopold (fluvial), Nye/Glen (glacial), Bagnold (wind),
  – Prediction – now a common goal

And, finally, the best reason of all to study geomorphology is that landscapes are simply fascinating and incredibly beautiful…

Understanding how they work only deepens one's appreciation of them.