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EART40011 Surface Processes

Dr. Dylan Rood
d.rood@imperial.ac.uk

Lecture 1: Geomorphology and Its Tools

An overview of what geomorphology is, how we do it, and why it matters

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Intended Learning Outcomes

By the end of the lecture, you should be able to:

1)**Understand** what geomorphology is and what disciplines it draws from

2)**Explain** how interactions among the geosphere, hydrosphere, and biosphere influence Earth surface processes at different spatial and temporal scales

3)**Identify** the tools that geomorphologists use to understand the form, changes, and history of Earth's surface, including: i) direct field observations and ii) indirect chemical, mathematical, physical, and isotopic approaches

4)**Demonstrate** how geomorphology data can be applied to solve "real-world" problems for society

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Outline

1) Introduction: What is Geomorphology and Why do we care?
2) Earth's Dynamic Surface
    1. Geosphere
    2. Hydrosphere
    3. Biosphere
    4. Landscapes: Spatial and Temporal Scales
    5. Unifying Concepts
3) Geomorphologist's Tool Kit
    1. Space: Characterizing Earth's surface
    2. Time: Dating Methods
    3. Measuring Rates of Geomorphic Processes
    4. Physical Models
    5. Proxy Records

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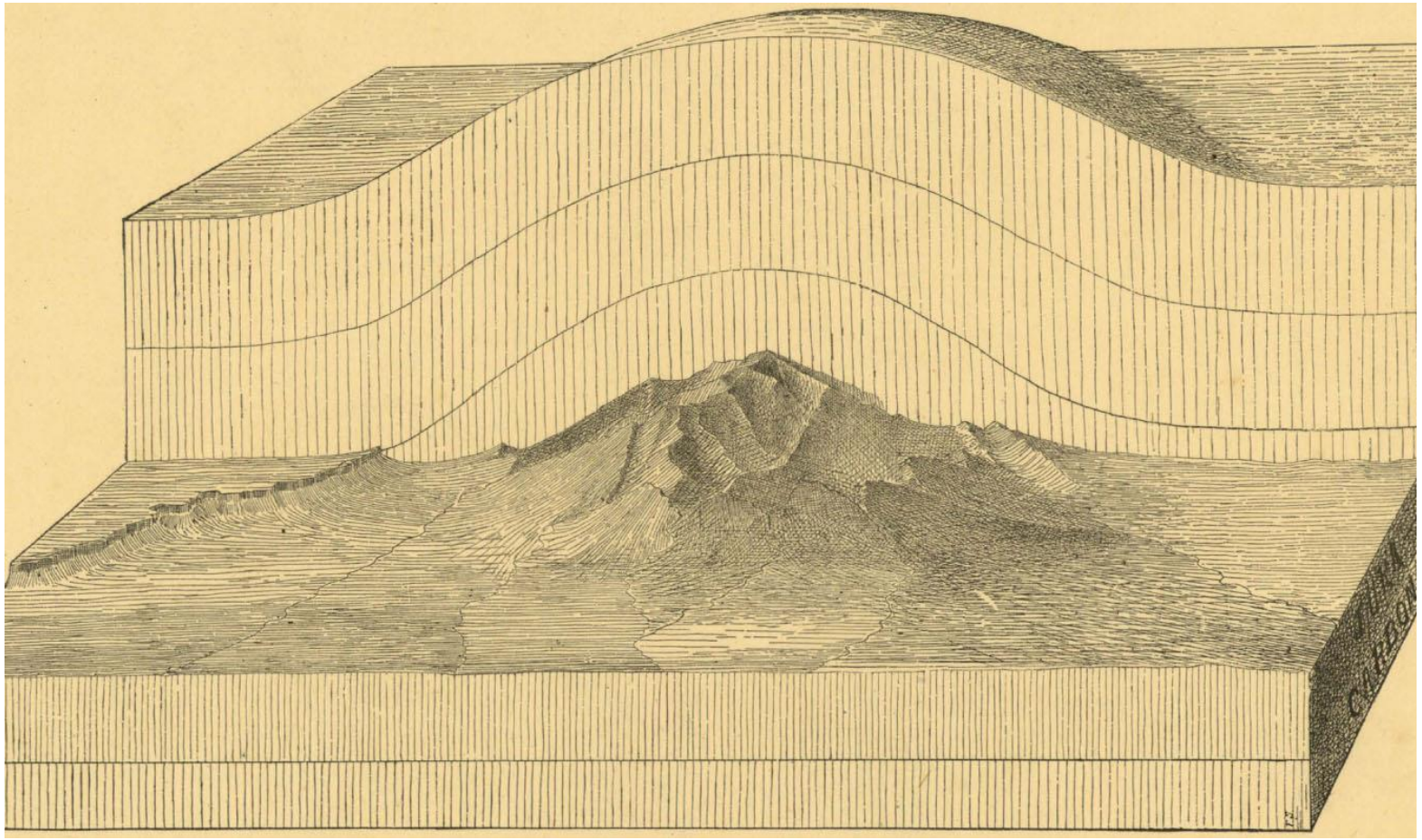
1. What is geomorphology?

Study of **processes** shaping Earth's surface and **landforms and deposits** they produce



(Gilbert, 1877)

1. What is Geomorphology? (cont.)

Multi-disciplinary:

1) Geology
2) Physics
3) Chemistry
4) Biology

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1. Why do we care?

Floods

Coastal erosion

Landslides

Rock falls

Debris flows

Earthquakes

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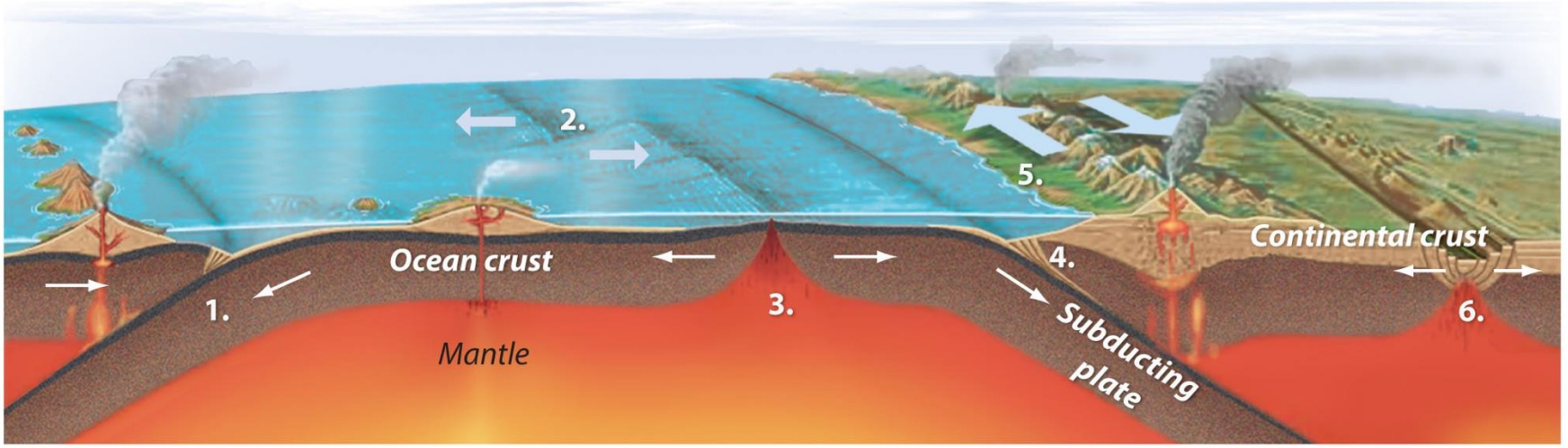
2. Earth's Dynamic Surface

Constantly changing and evolving:

Endogenic processes

Exogenic processes



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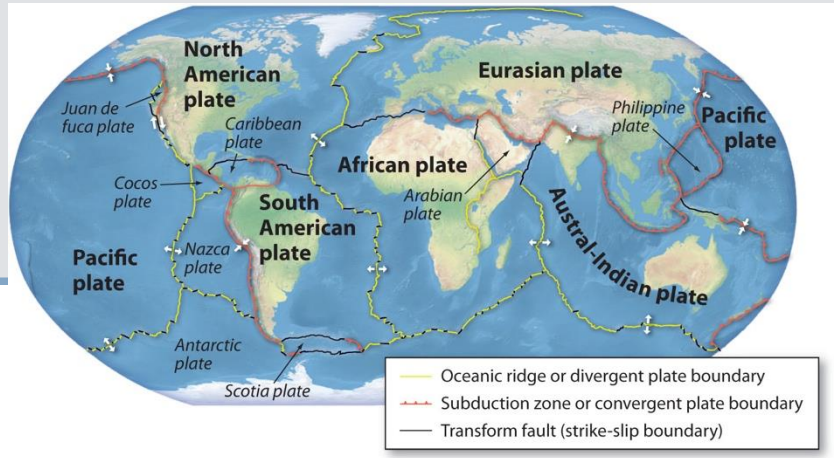
2.1 Geosphere

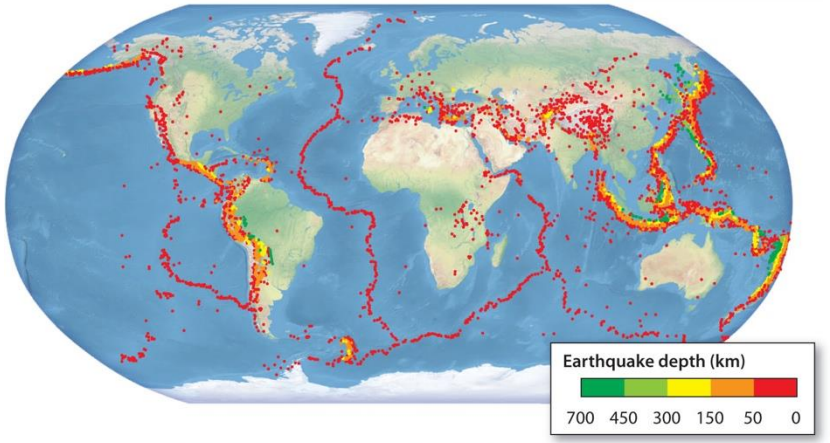
Plate tectonics

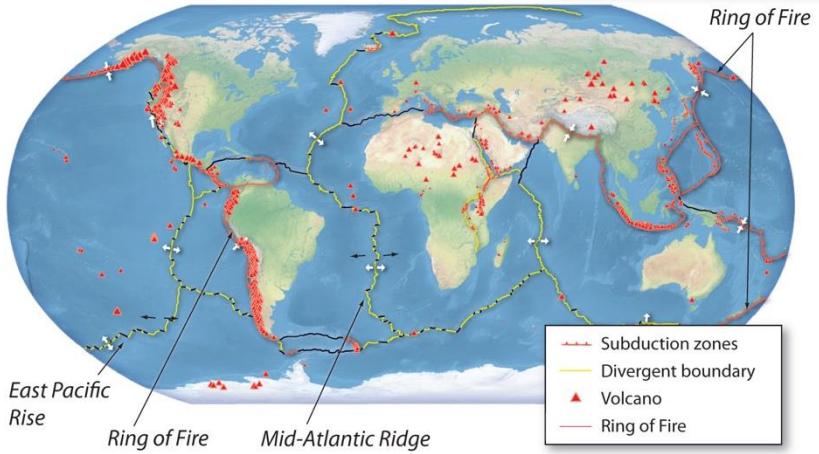
1) *topography*

2) *rates and styles*

3) rock types







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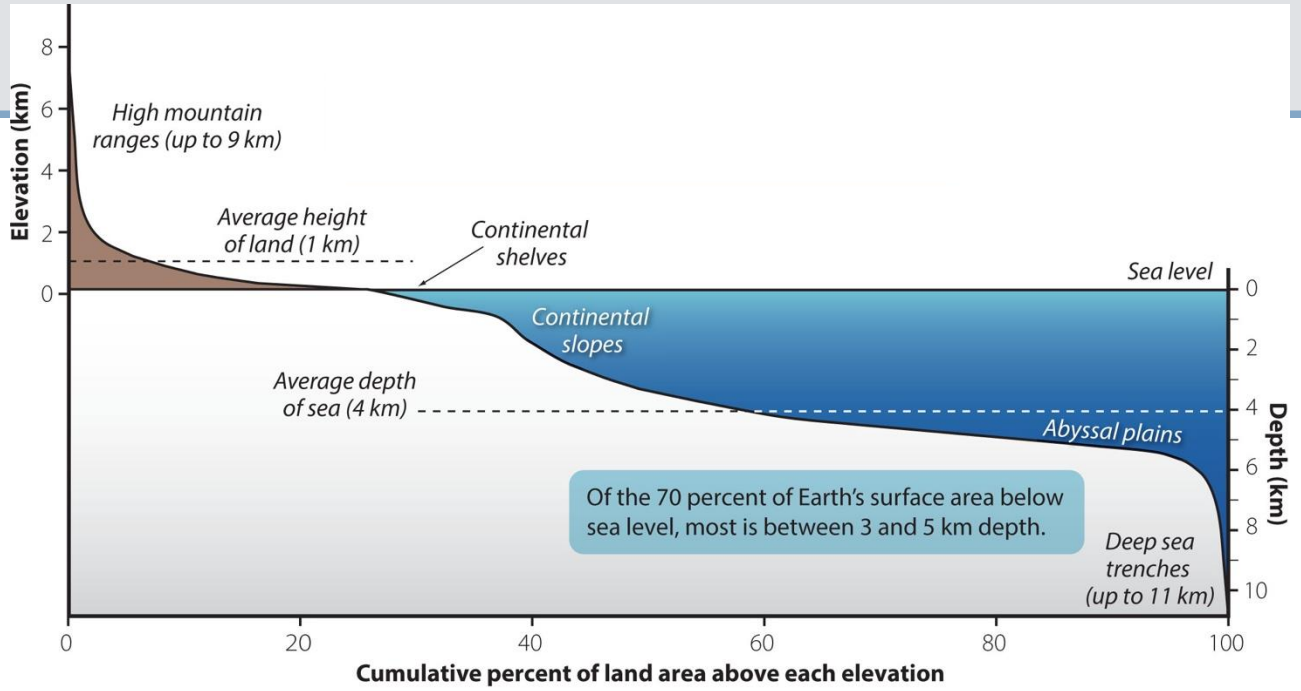
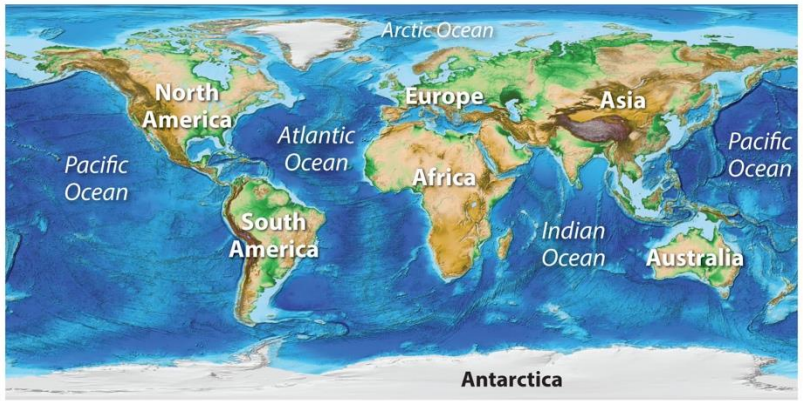
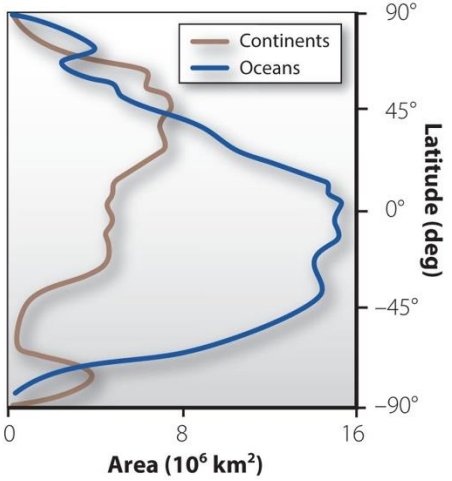
2.1 Geosphere

Density and thickness

(i.e. isostasy)







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2.1 Geosphere

Lithology (rock type)

Structure

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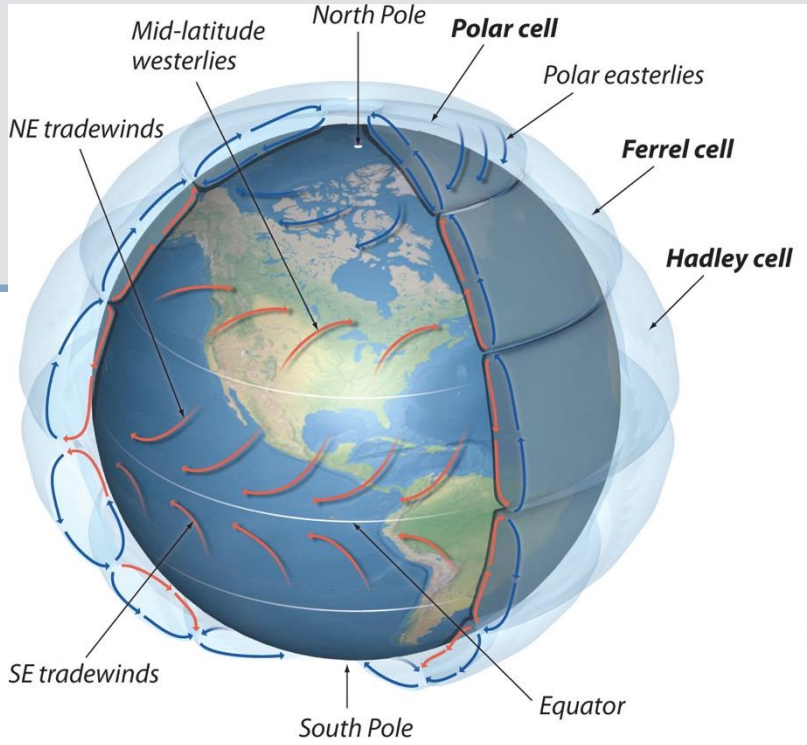
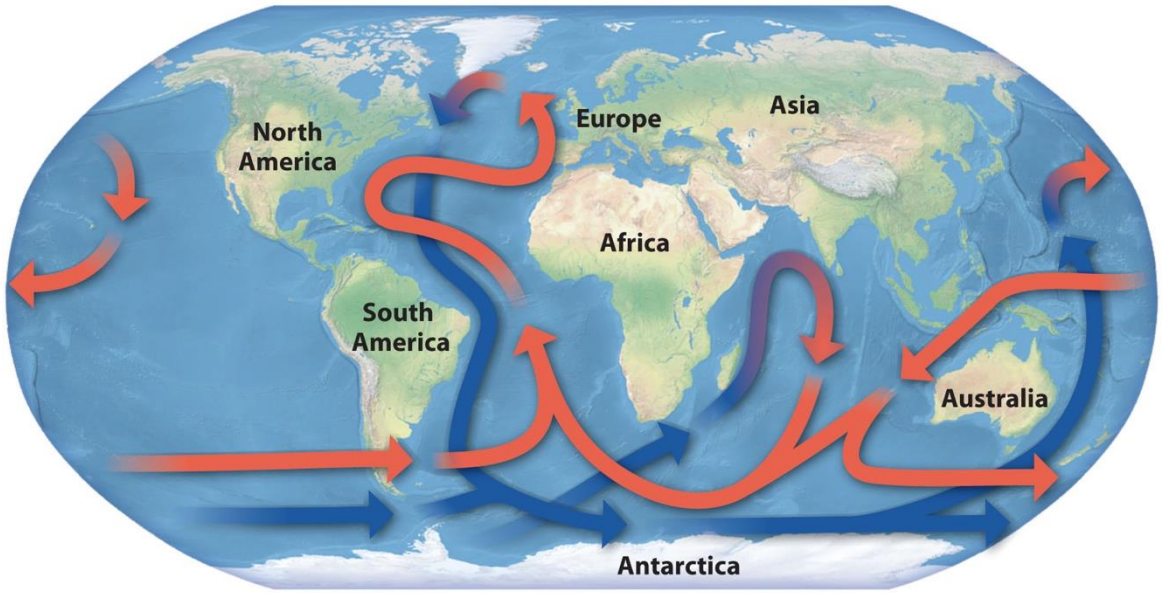
2.2 Hydrosphere

Water

Insolation
(amount of Sun's energy)

Albedo
(reflectivity)





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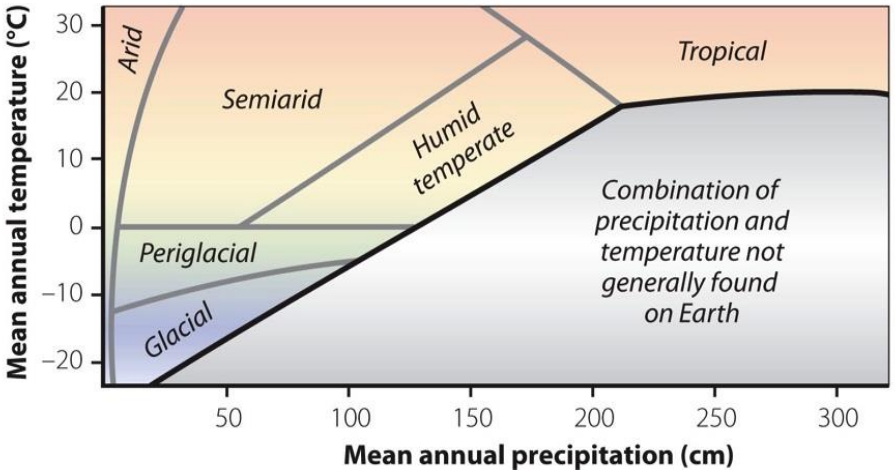
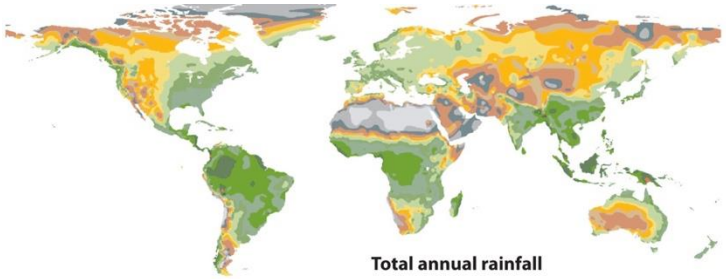
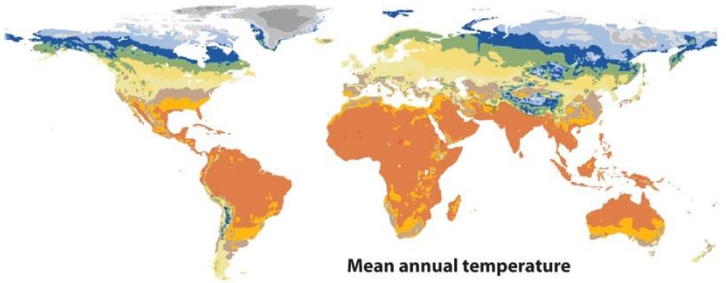
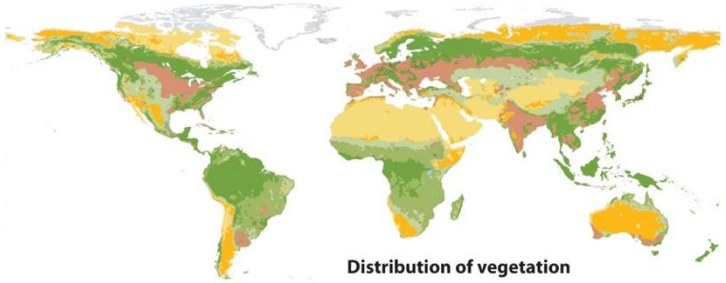
2.2 Hydrosphere

Climate









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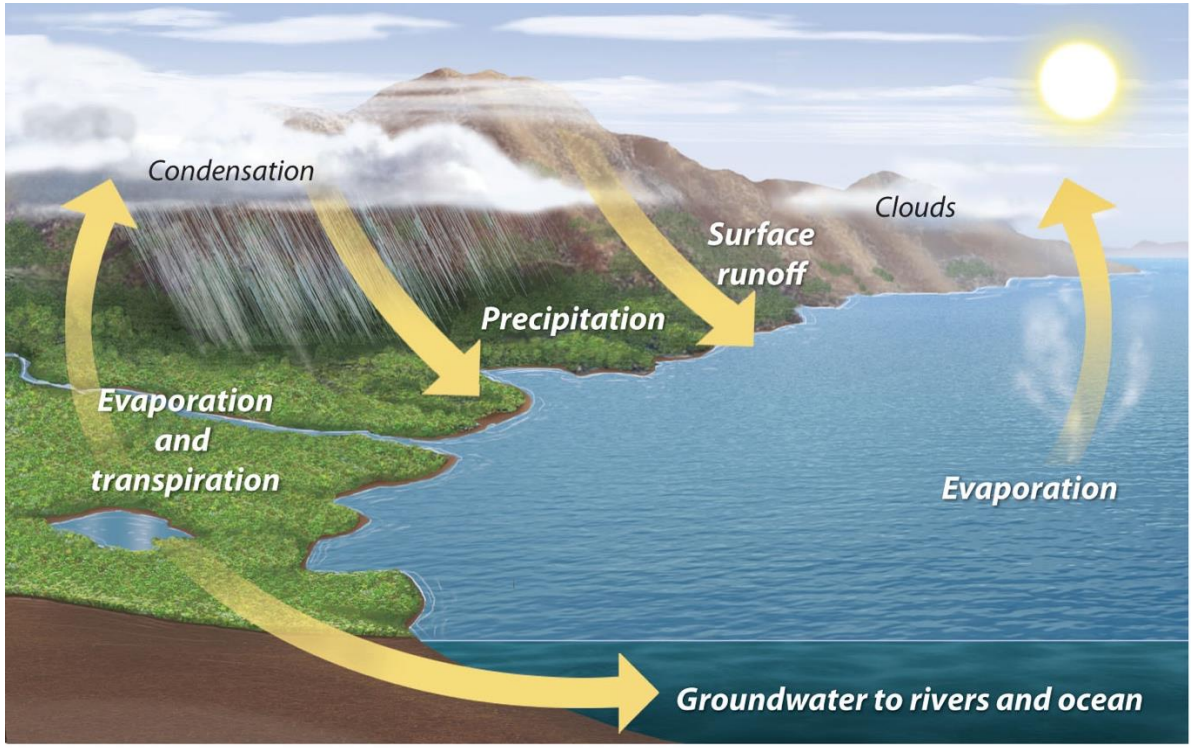
2.2 Hydrosphere

Elevation

Orographic effects (e.g. rain shadows)



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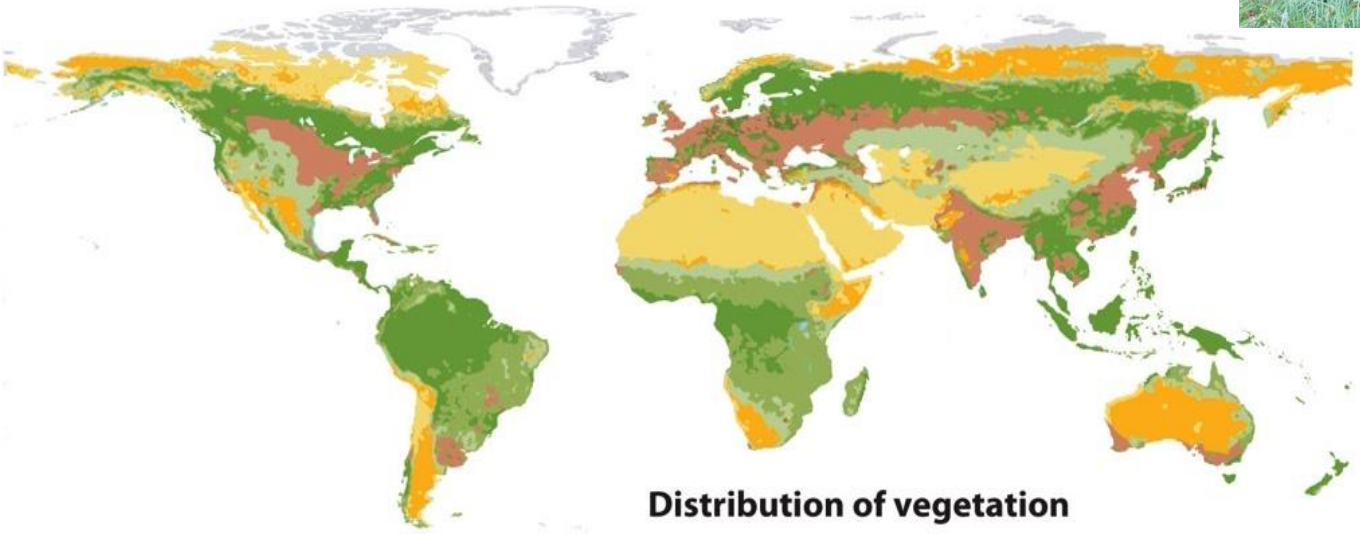
2.3 Biosphere

Variety of scales

Tracks climate zones

- -5 broad vegetation zones
- -Distinctive properties



Distribution of vegetation

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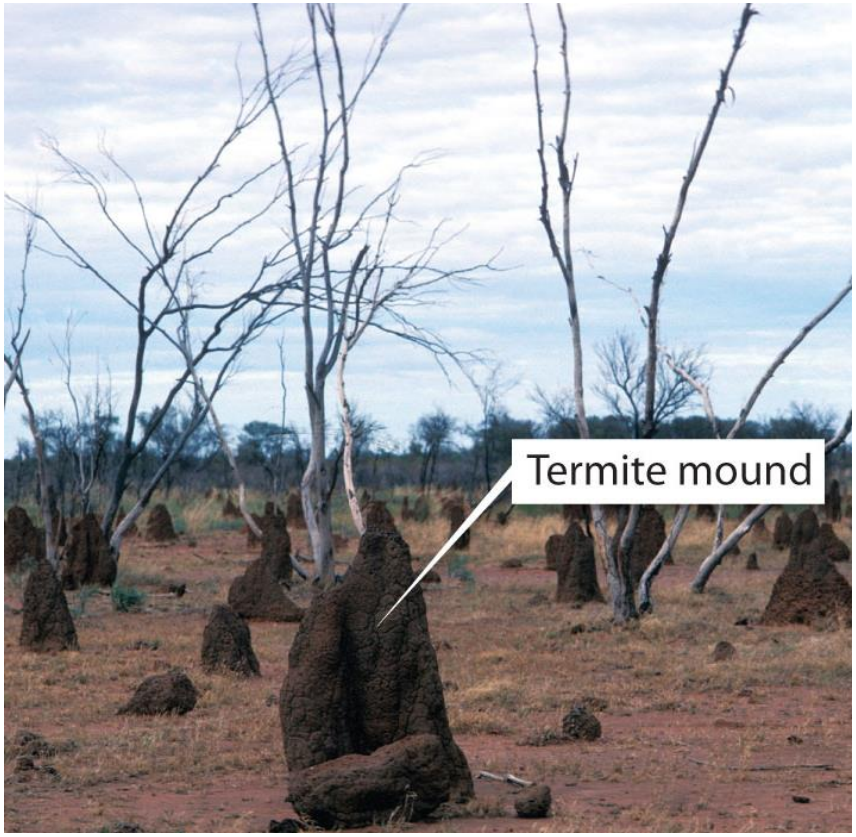
2.3 Biosphere

Animals



Humans

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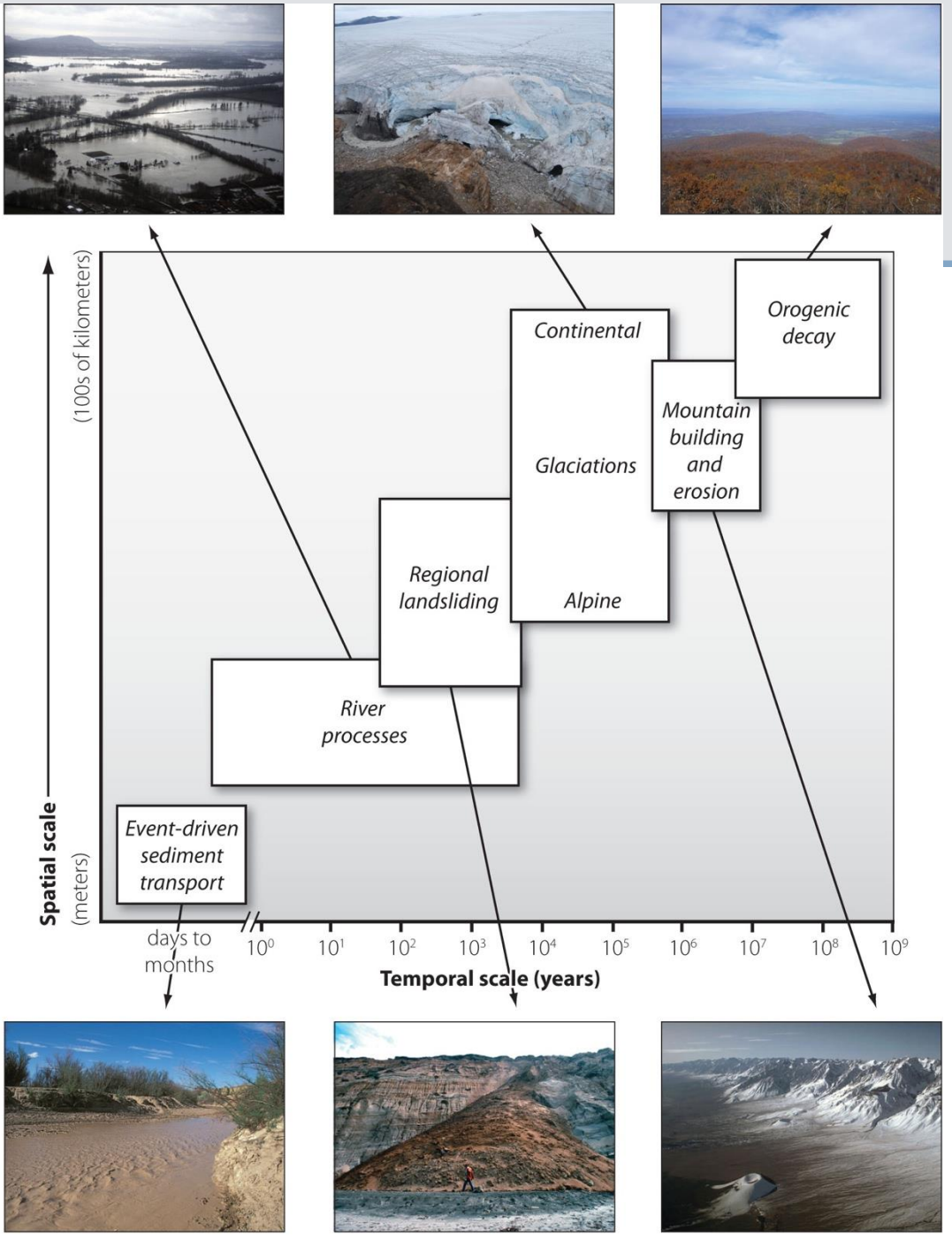
2.4 Landscapes

Wide range of spatial and temporal scales



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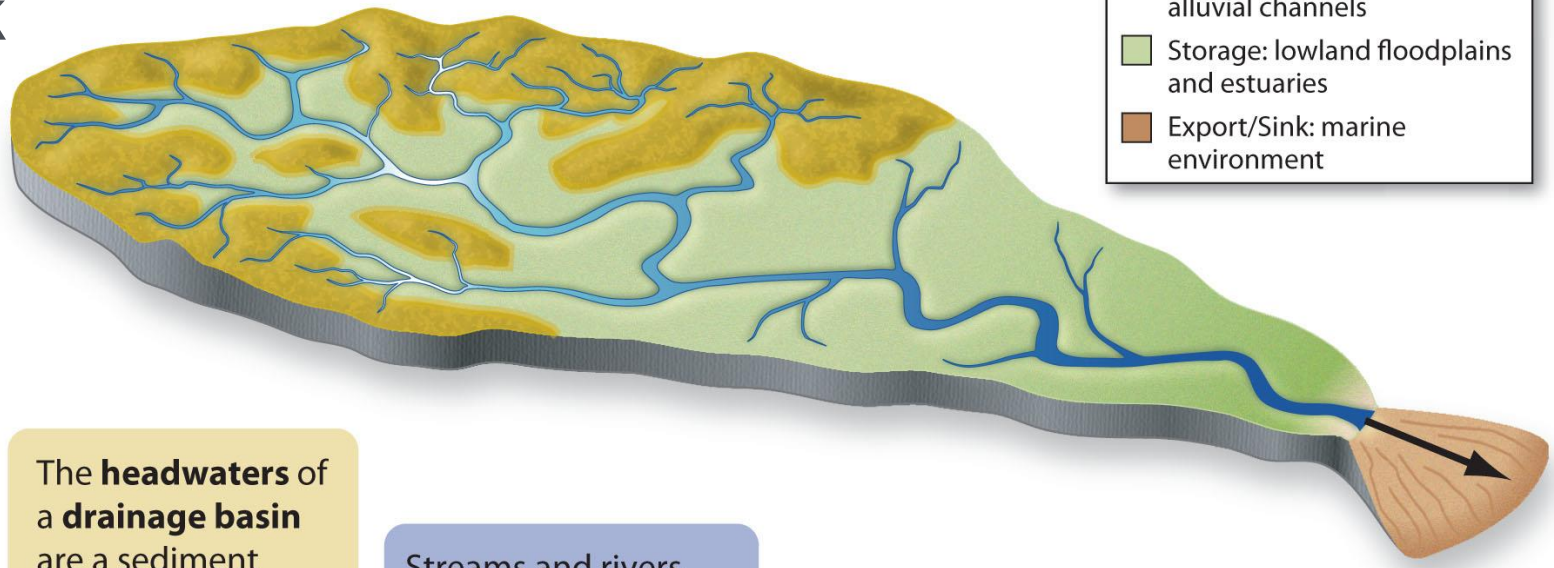
2.5 Unifying Concepts

3. Material Routing – Source to Sink



The **headwaters** of a **drainage basin** are a sediment source where weathering breaks down rocks and erosional processes deliver sediment to streams and rivers.

Streams and rivers both transport and store material through the interchange of sediment in transport with that stored in **floodplains.**

Lowland floodplains and **estuaries** are long-term depositional areas where sediment inputs may exceed sediment outputs.

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

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2.5 Unifying Concepts

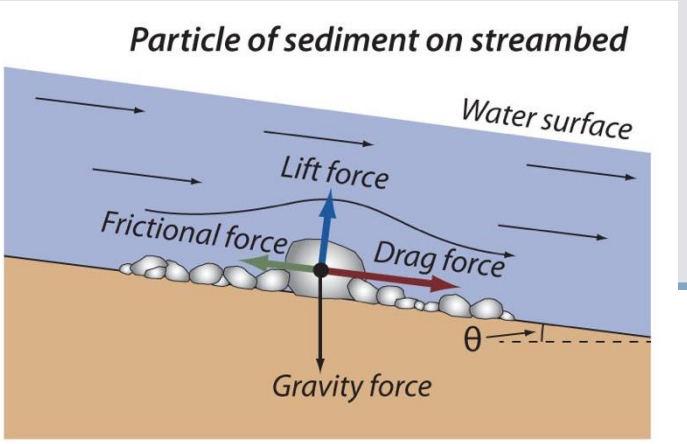
4. Force Balance and Thresholds

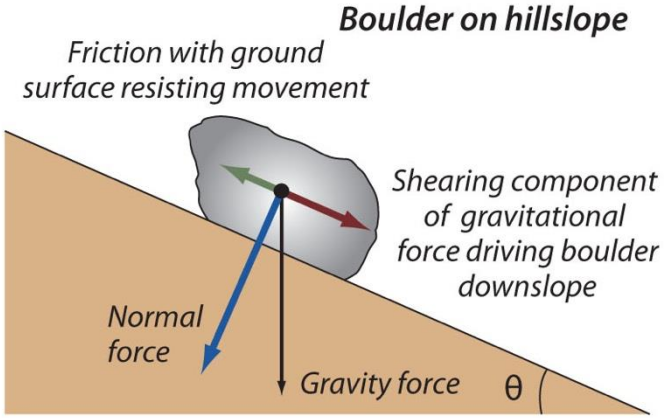
-Normal (blue)

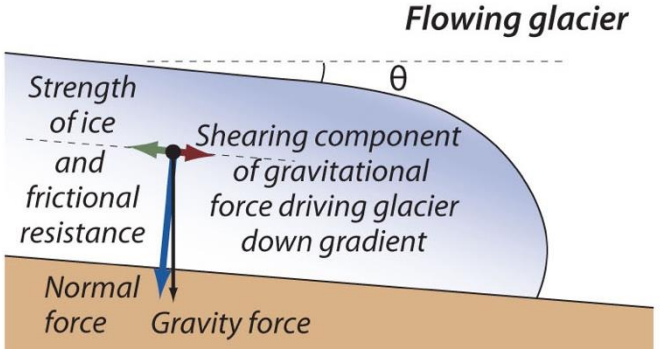
$\rho g z \cos \theta$

-Shear (red)

$\rho g z \sin \theta$



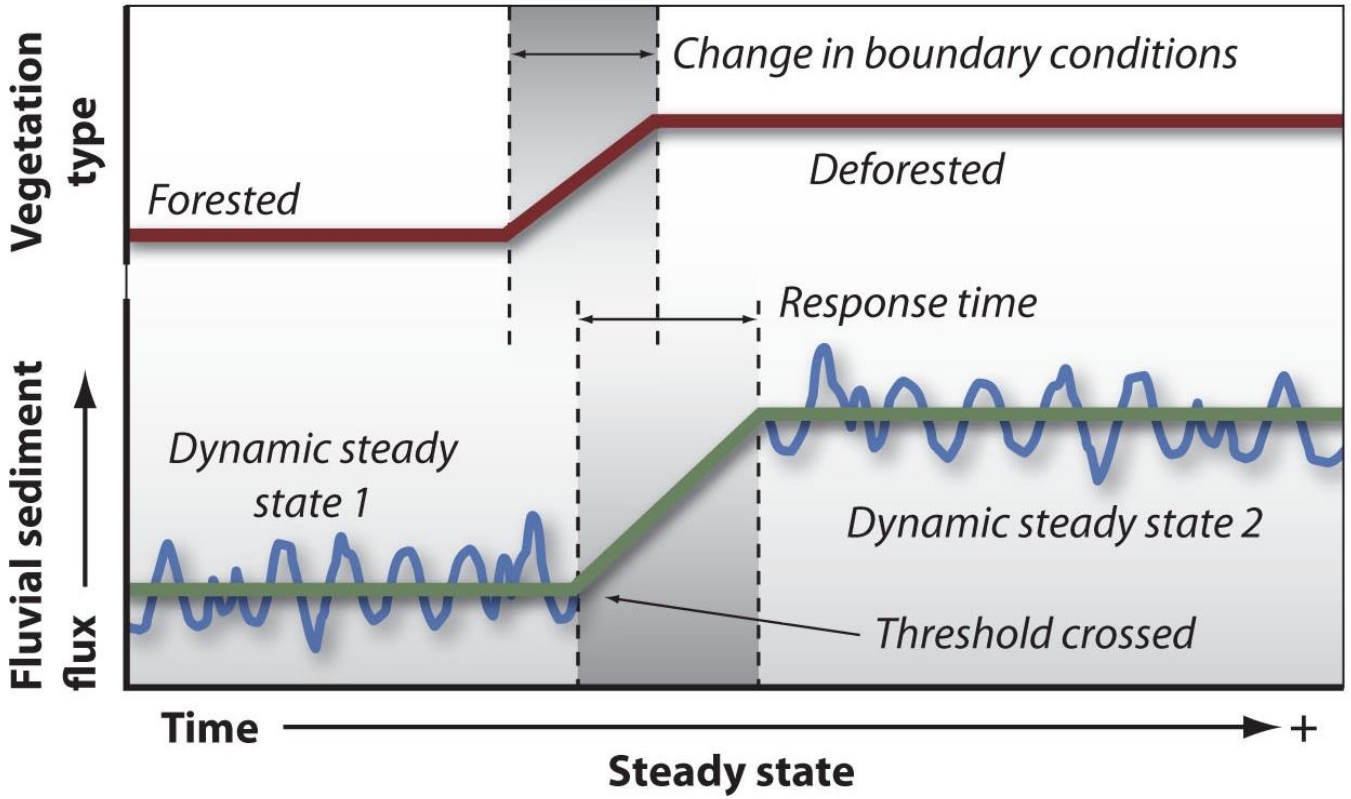




2.5 Unifying Concepts 4. Force Balance and Thresholds

Threshold

Response time

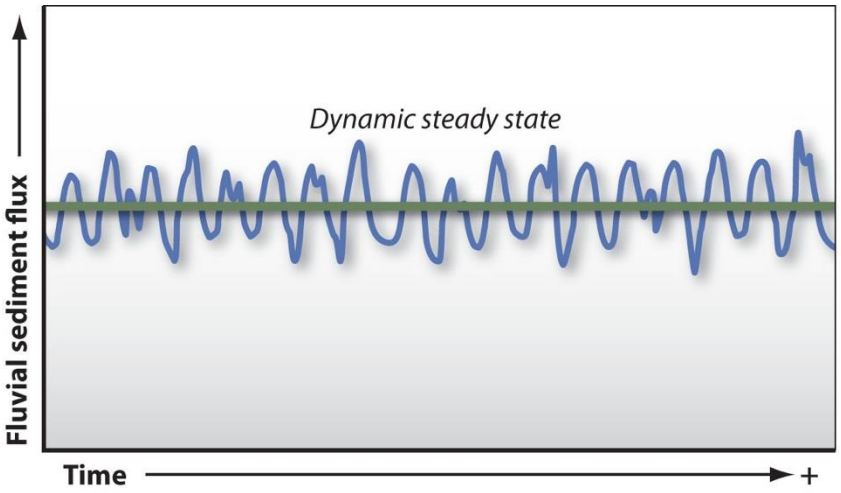


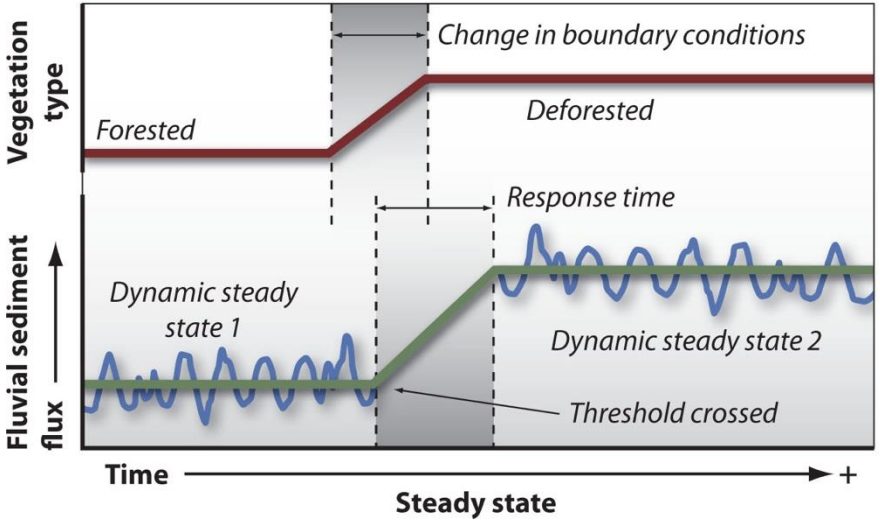
2.5 Unifying Concepts

5. Equilibrium and Steady State

Dynamic steady state

Dynamic equilibrium





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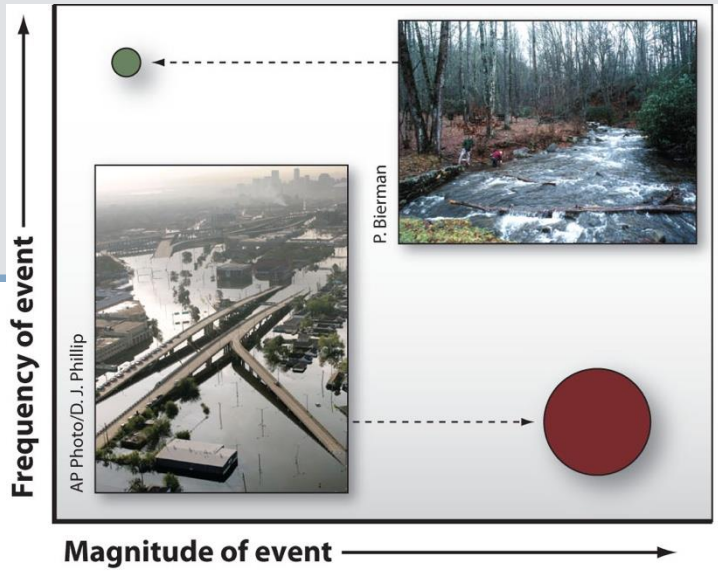
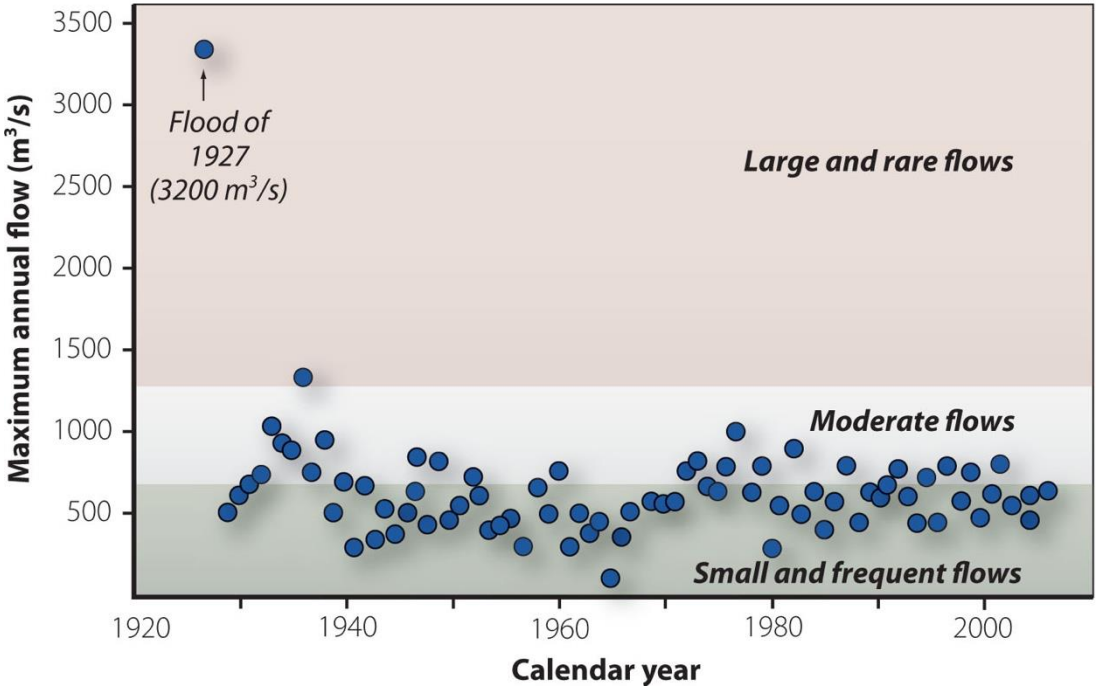
2.5 Unifying Concepts

6. Recurrence Intervals and Magnitude-Frequency Relationships





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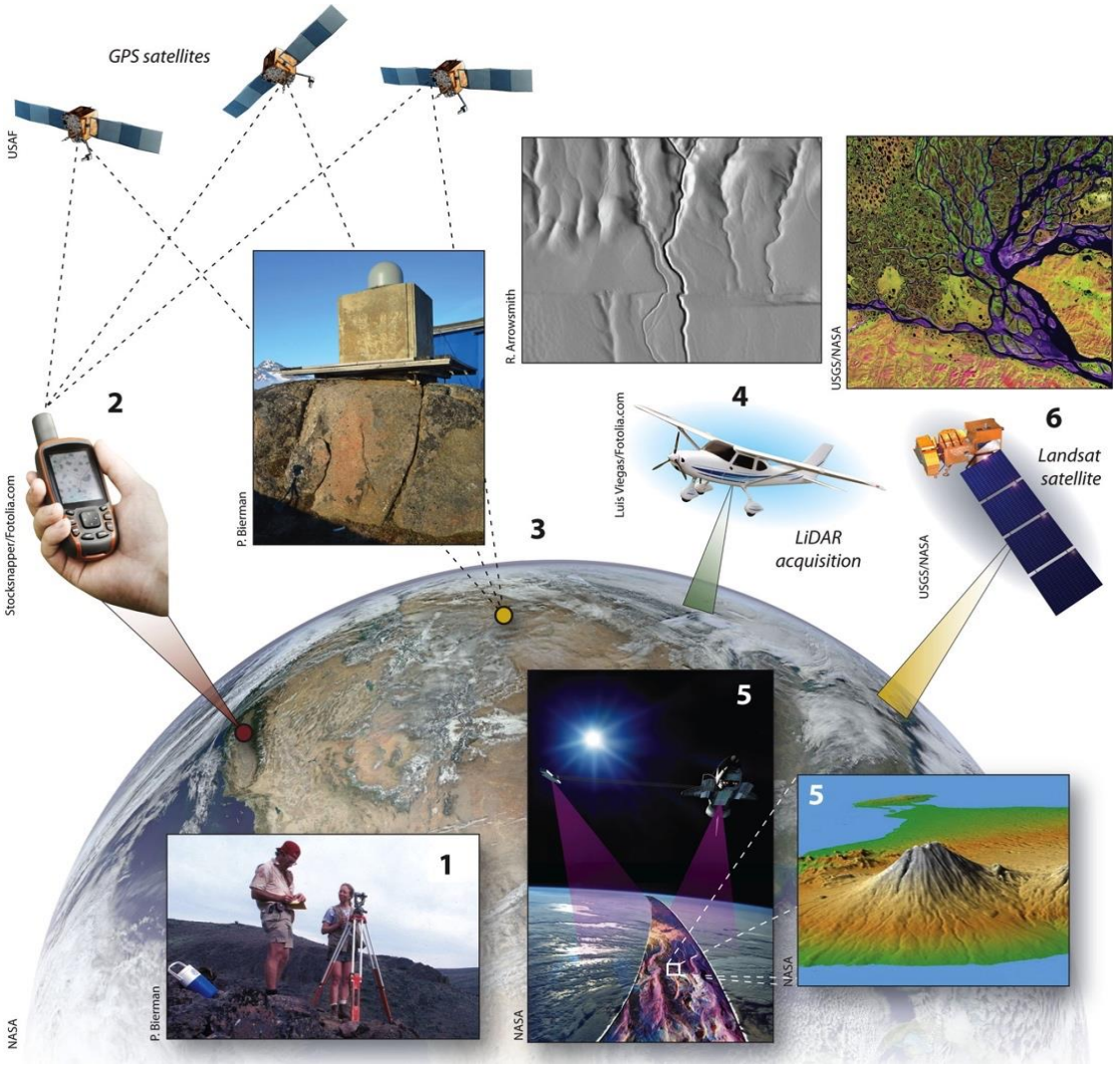
3.1 Space: Characterizing Earth's Surface

Field Surveys

Active Remote Sensing

Passive Remote Sensing

Digital Topography



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3.2 Dating Methods

Either Relative or Numerical

Dating methods frequently used by geomorphologists

Method	Type	Age Range (years)	Requirements/Assumptions
Radiocarbon (^{14}C)	Numeric dating	10^2 to 5×10^4	Organic material present in interpretable geologic context
Cosmogenic nuclides	Numeric dating	10^2 to 10^6	Continuous exposure of noneroding surface that was free of cosmogenic nuclides before exposure
Luminescence	Numeric dating	10^3 to 10^6	Quartz or feldspar exposed to light or heat before burial
U/Th	Numeric dating	10^3 to 10^5	Carbonate minerals
Dendrochronology	Numeric dating	10^0 to 10^4	Wood from trees
K/Ar	Numeric dating	10^3 to 10^8	Potassium-bearing minerals
Lichenometry	Calibrated relative dating	10^1 to 10^3	Lichens on both unknown and dated calibration sites
Amino-acid racemization	Calibrated relative dating	10^3 to 10^5	Well-preserved shell material
Rock weathering	Relative dating	10^2 to 10^4	Dated surfaces for calibration
Soil development	Relative dating	10^2 to 10^6	Dated chronosequence for calibration

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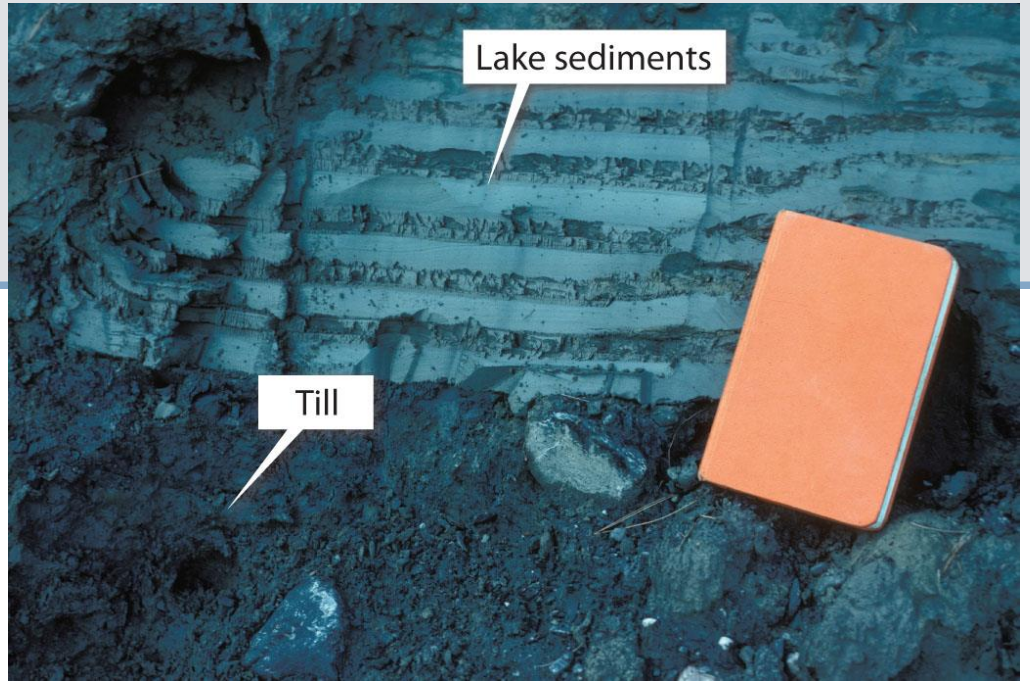
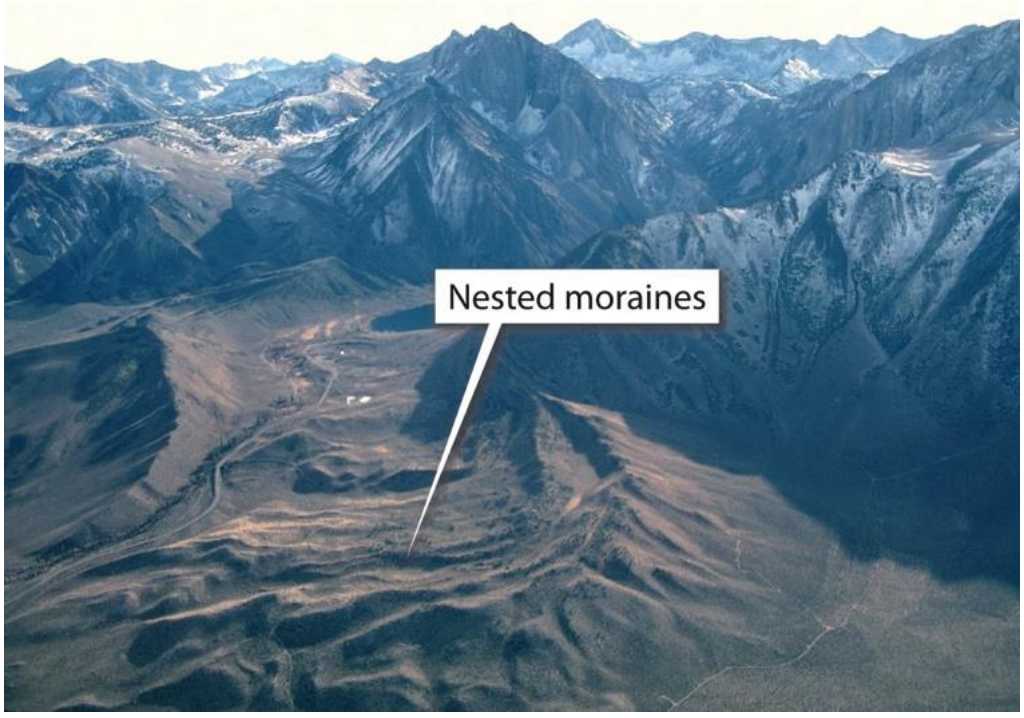
3.2 Time: Dating Methods

1. Relative Dating Methods

1) Chronosequence

2) Superposition and cross-cutting relationships





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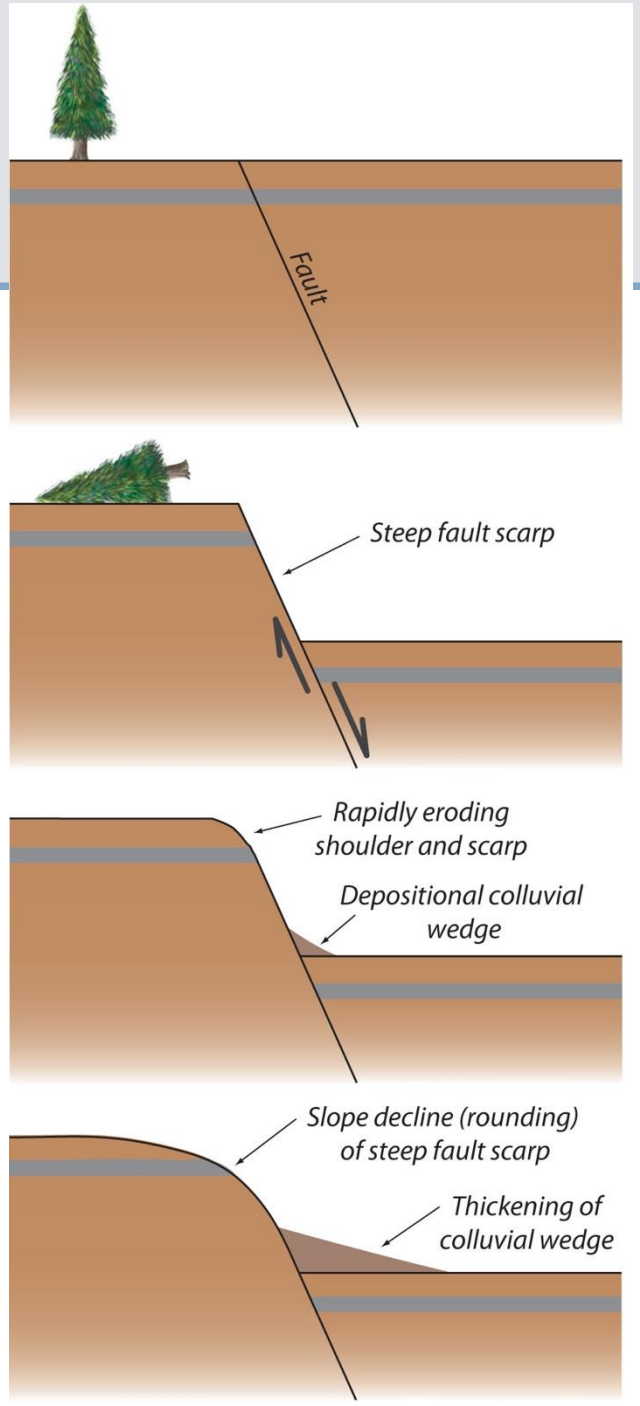
3.2 Time: Dating Methods

1. Relative Dating Methods (cont.)

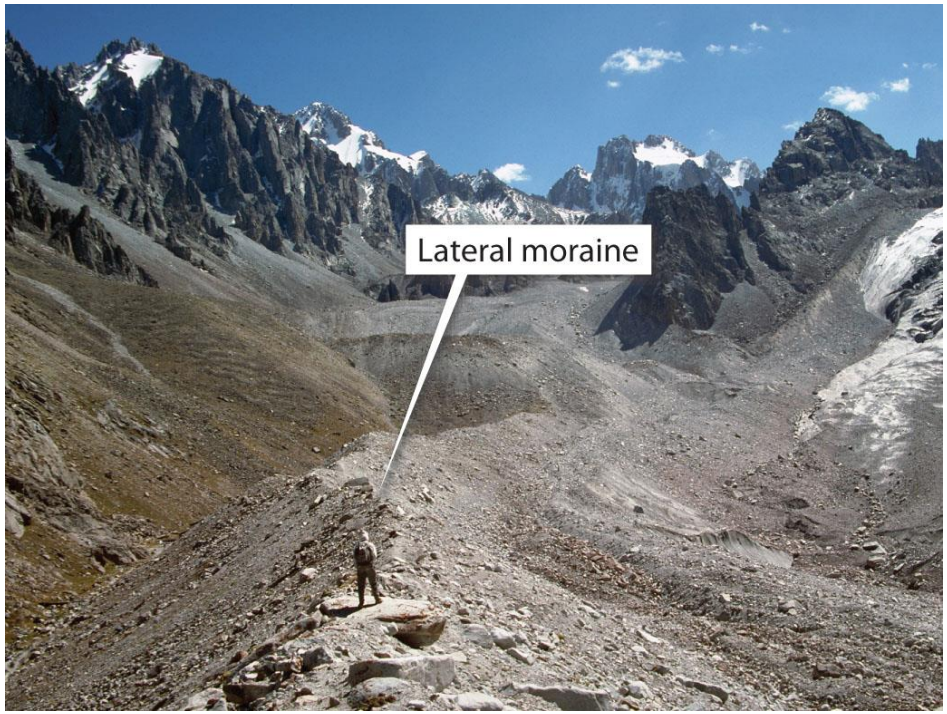
3) Landform Degradation



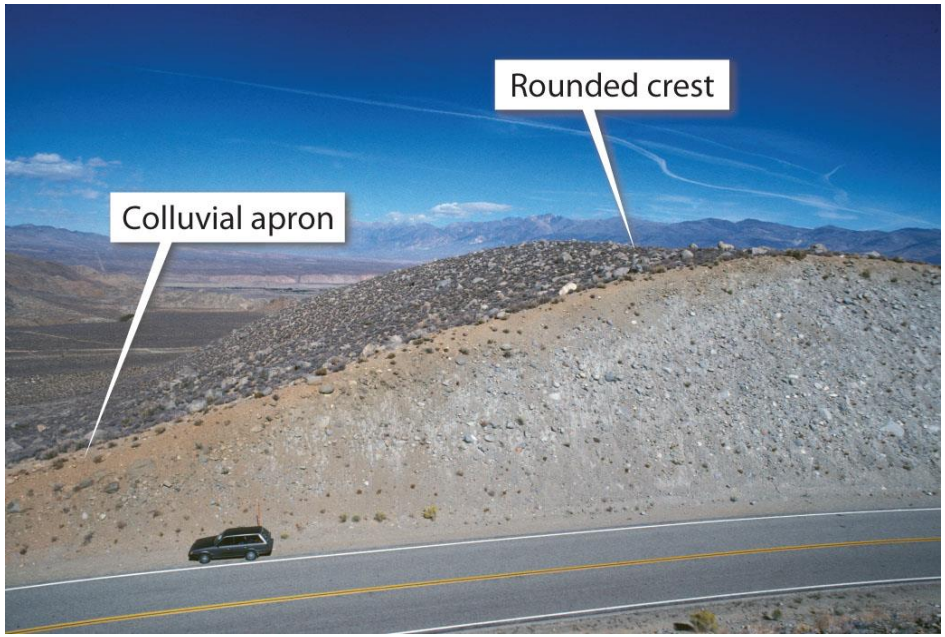
3.2 Time: Dating Methods

3) Landform Degradation (cont.)

Young moraine



Old moraine



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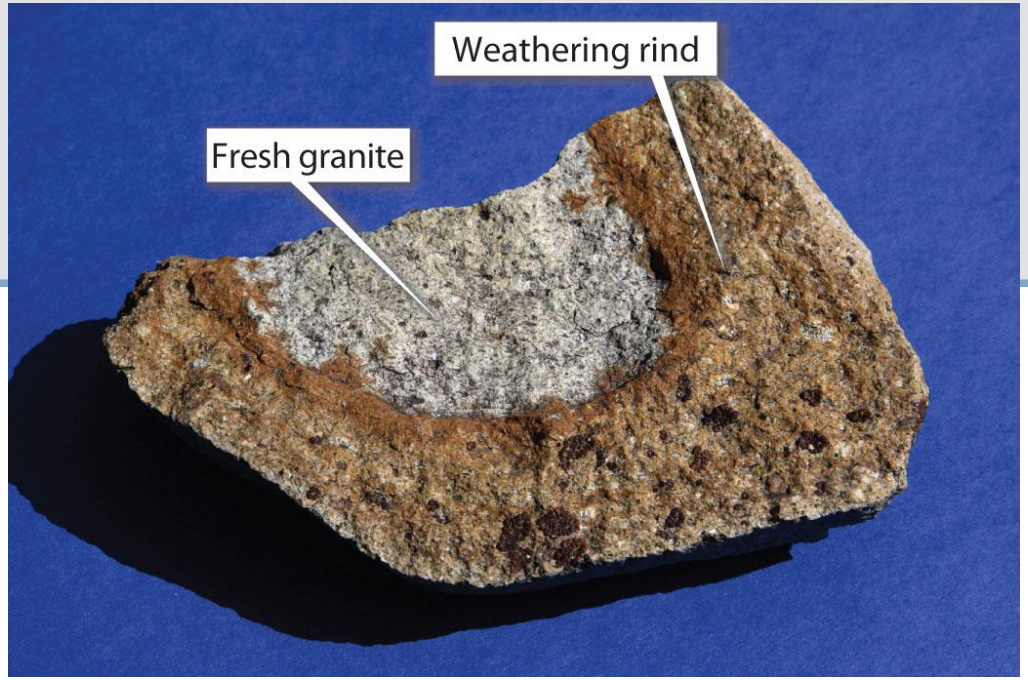
3.2 Time: Dating Methods

1. Relative Dating Methods (cont.)

4) Rock Weathering and Soil Development

5) Rock varnish (aka desert varnish)



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3.2 Dating Methods

Dating methods frequently used by geomorphologists

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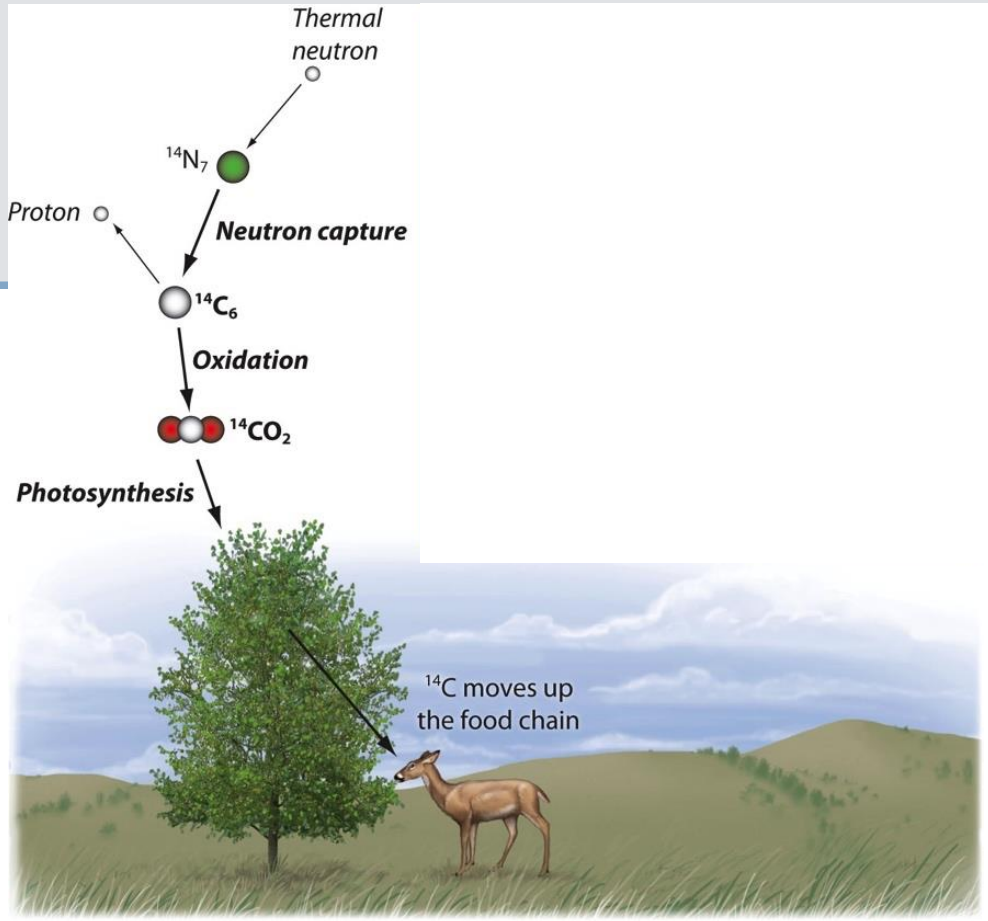
3.2 Dating Methods

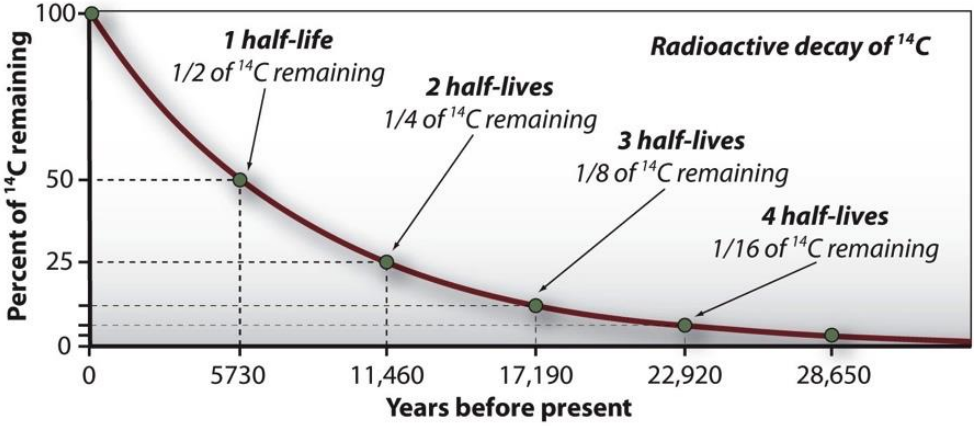
2. Numerical Dating Methods

1) Radiocarbon Dating

$$N(t) = N_0 e^{-\lambda t}$$

Where N=number of nuclides, N_0=initial number of nuclides, λ=**decay constant** (reciprocal of **mean life**), t=time



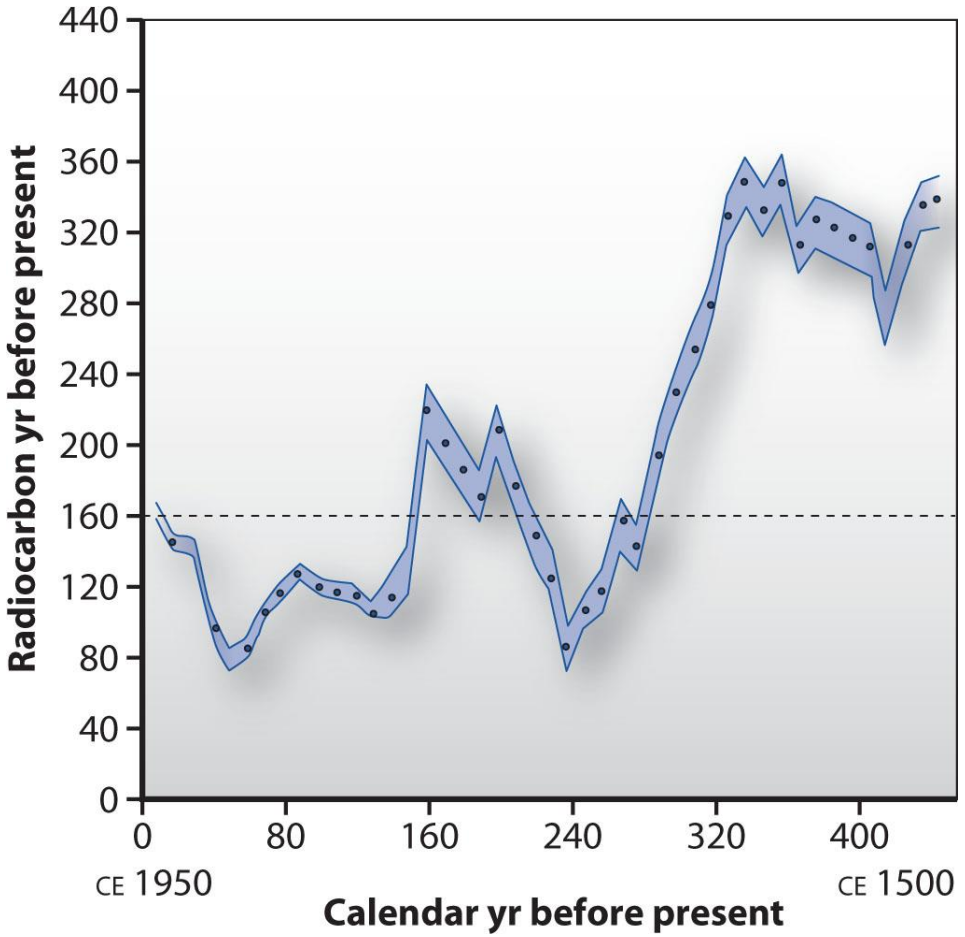


3.2 Dating Methods

1) Radiocarbon Dating (cont.)

Radiocarbon age (years) = 8033 ln (1/pmC)

where **mean life (τ)**=8033 years



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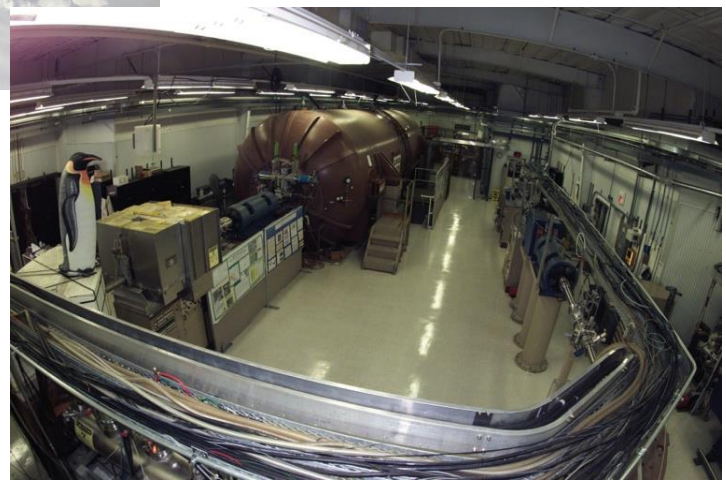
3.2 Dating Methods

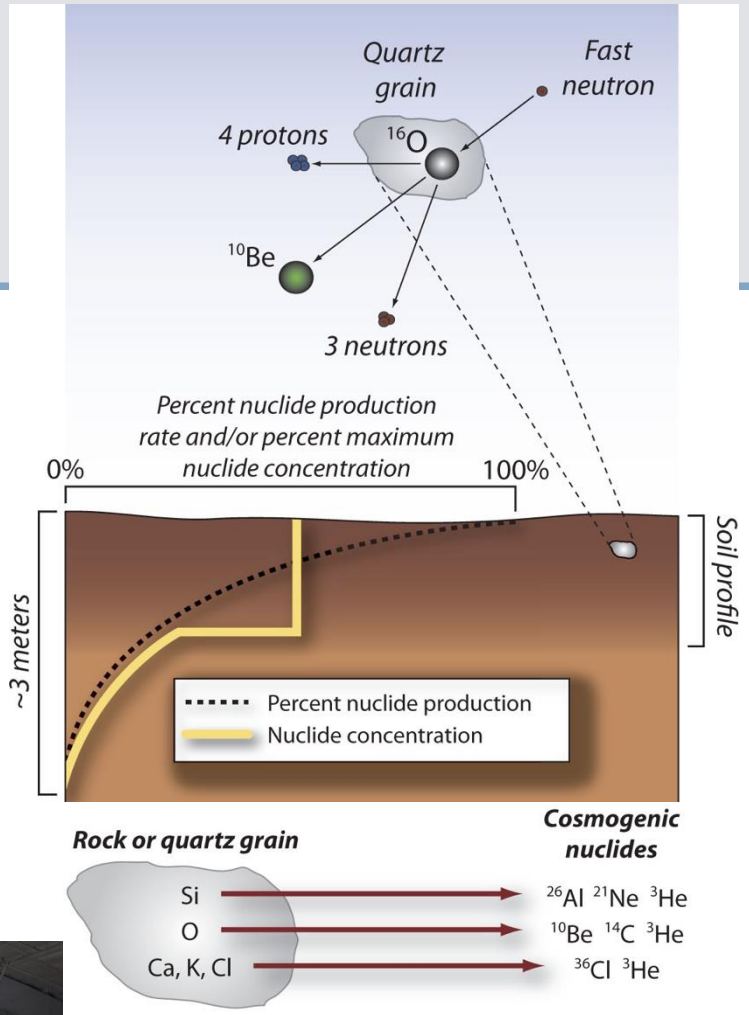
2. Numerical Dating Methods (cont.)

2) In-Situ Cosmogenic Nuclides

(left) Field sampling of glacial erratic



(right) Measurement by Accelerator Mass Spectrometry (AMS)



3.2 Dating Methods

3) In-Situ Cosmogenic Nuclides (cont.)

$$\frac{^{10}Be\ (atoms)}{^{9}Be\ (atoms)} \times {}^{9}Be\ (atoms) = Total\ ^{10}Be\ (atoms)\ in\ sample$$

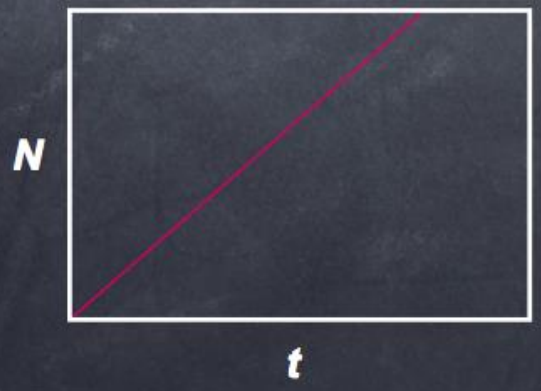
$$\frac{^{10}Be\ (atoms)}{Quartz\ (g)} = N\ (atoms/g)$$

Exposure dating

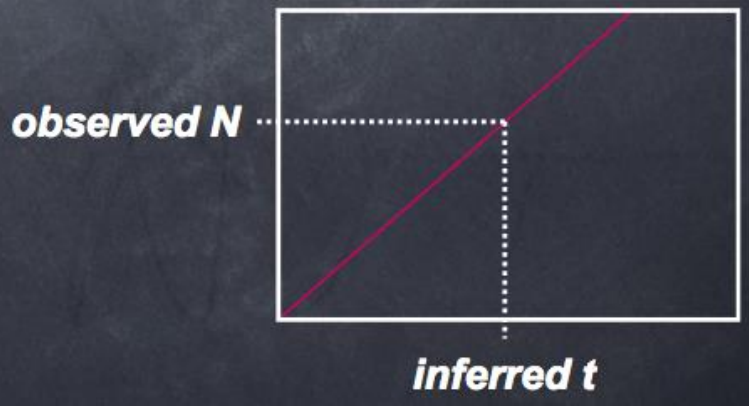
Forward model:

$N = Pt$

N concentration (atoms/g)
P production (atoms/g/yr)
t exposure time (yr)



Inversion: t = N/P



Erosion Rates

$$N = \frac{P_0}{\lambda + \frac{\varepsilon}{\Lambda_{sp}}}$$

P_0 = production rate at surface (atoms/g/yr)
ε = erosion rate (g/cm^2/yr)
λ = decay constant (/yr)
Λ_{sp} = attenuation length for spallation (g/cm^2)

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3.3 Measuring Rates of Geomorphic Processes

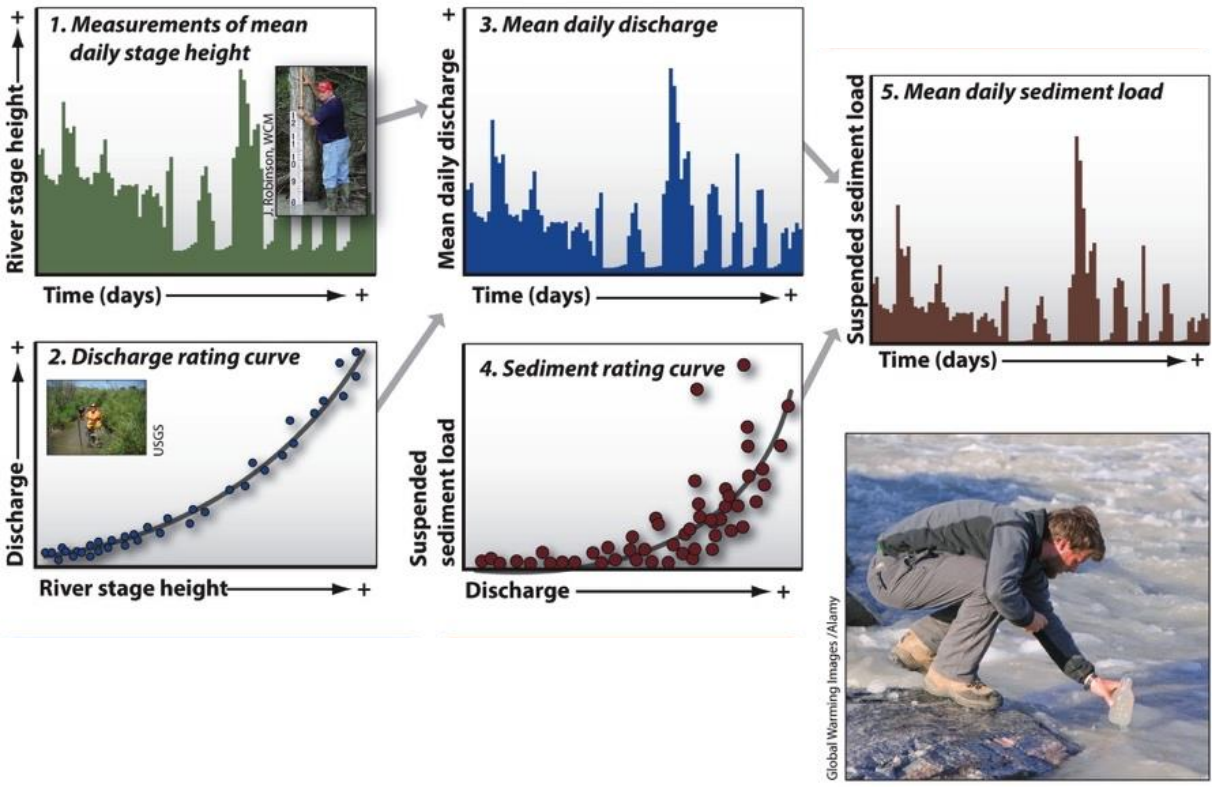
Integration time

Short Timescales
(10^{-1}-10^{2} yrs)

1) **Sediment yield**

- **Stage**

2) **Sediment volumes**



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3.3 Measuring Rates of Geomorphic Processes

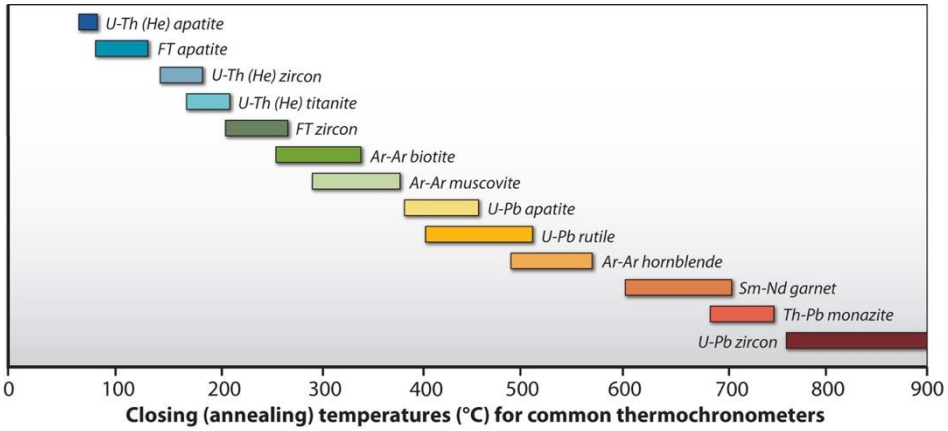
Intermediate Timescales (10^3-10^5 yrs)

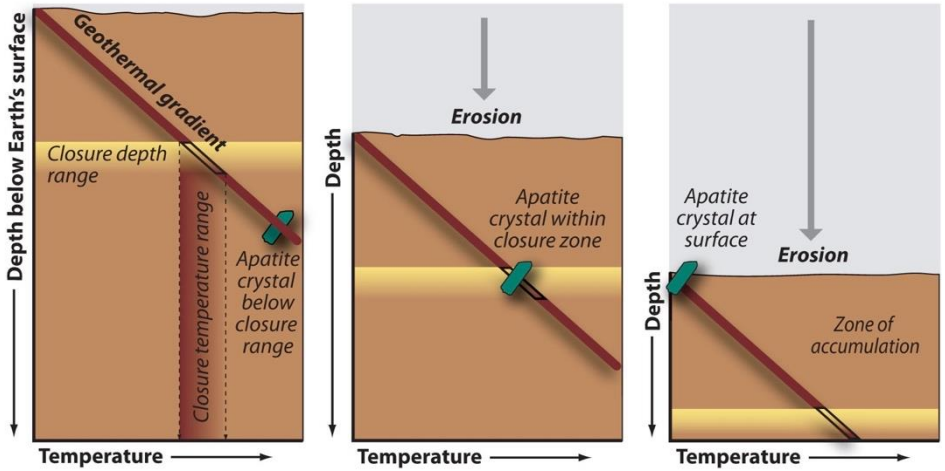
3) **Cosmogenic isotopes**

4) **Natural basins**

Long Timescales (10^6-10^8 yrs)

5) **Thermochronology**





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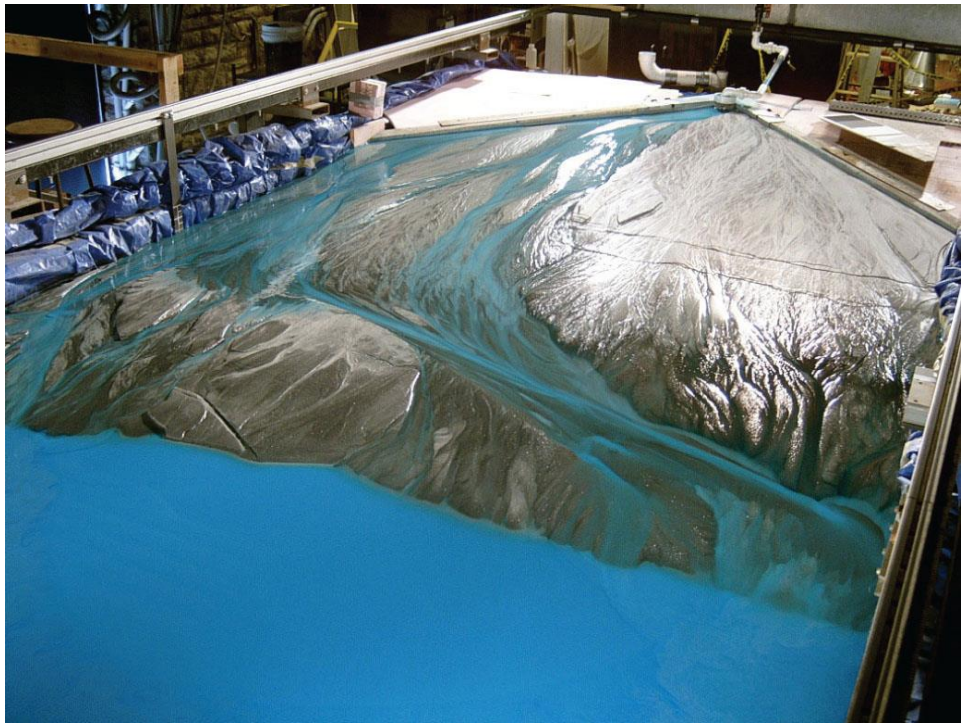
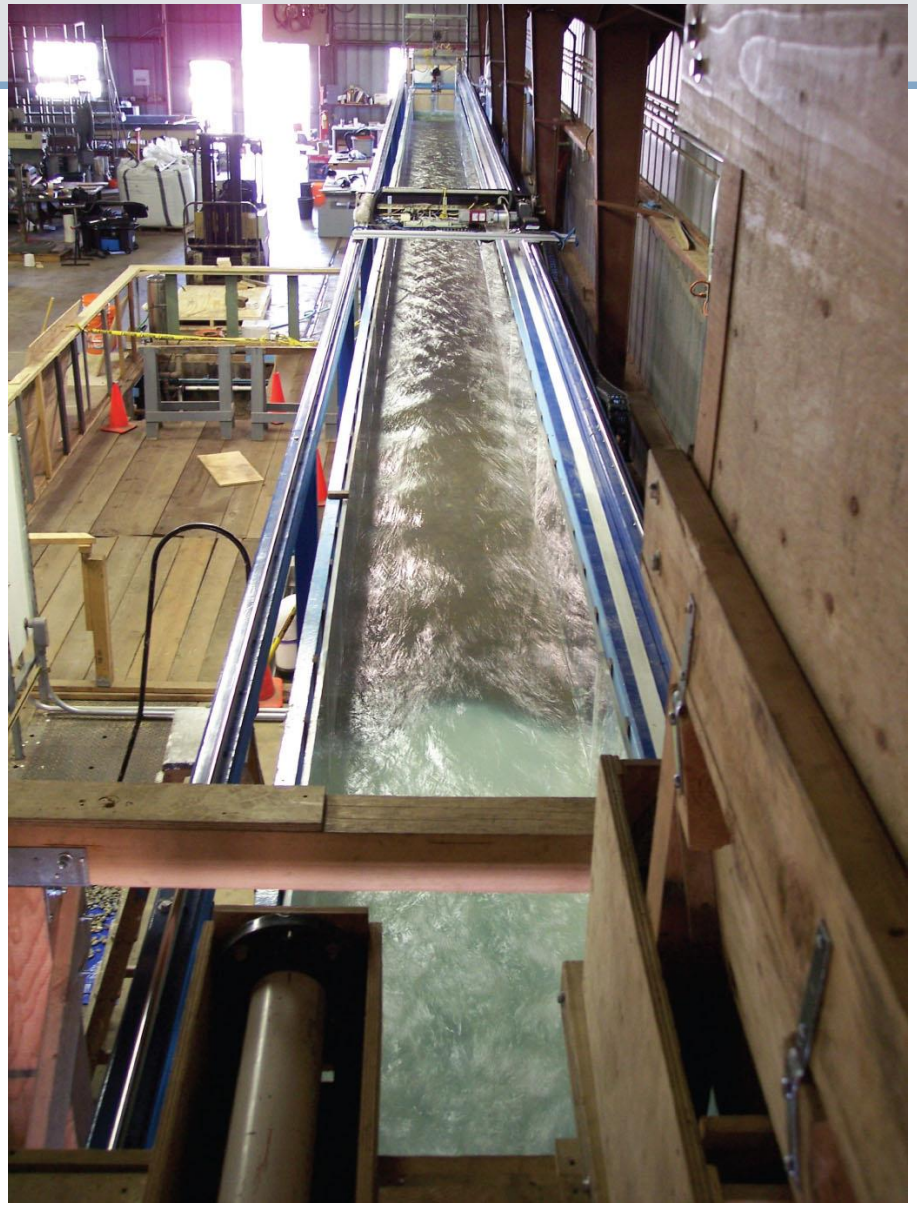
3.4 Physical Models

1) **Analog experiments**

- **Scaling**

2) **Numerical Models**





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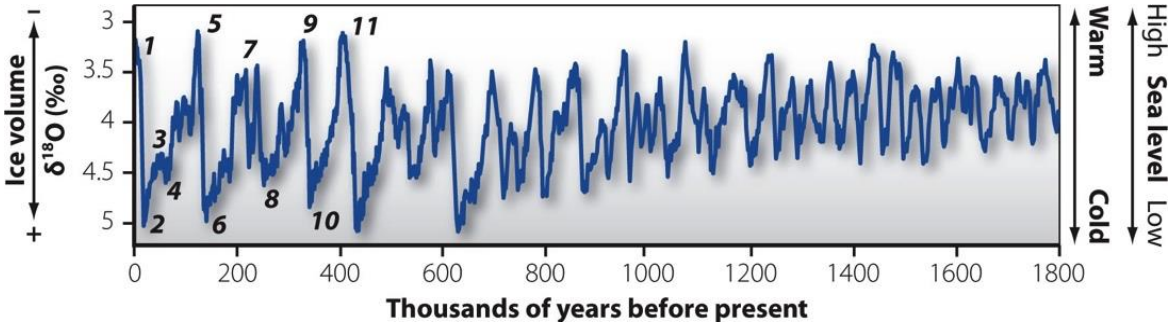
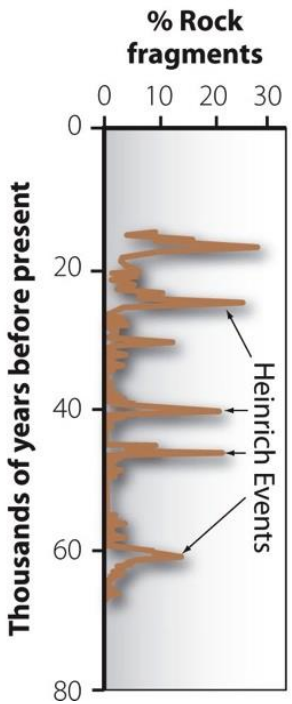
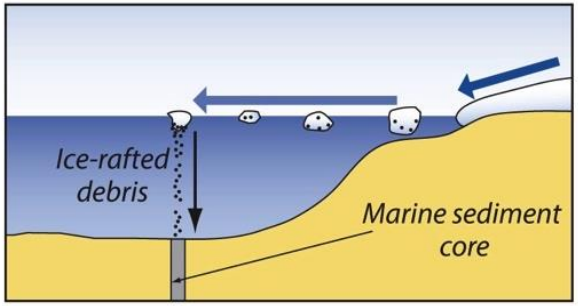
3.5 Proxy Records

Cannot be interpreted <u>directly</u>

Rely on **<u>transfer functions</u>**







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Lecture Summary

Geomorphology is the study of the **processes** shaping Earth's surface and the **landforms and deposits** that they produce. Geomorphologists observe and interpret landscapes in order to understand how processes shape Earth's surface, decipher **Earth history**, and recognize, mitigate, and manage impacts of **environmental hazards on society**. Geomorphology is synthetic and draws from **geology, physics, chemistry, and biology**.

Earth's surface is **dynamic** and shaped by processes driven by interactions among the **geosphere, hydrosphere, and biosphere**; processes that operate over **multiple temporal and spatial scales** and are linked by **unifying concepts**.

Geomorphologists use a variety of direct and indirect tools to observe and reconstruct Earth's surface processes and history, including **observations of Earth's surface, methods allowing quantification of dates and rates of processes, physical models**, and **proxy records**.