16. Sediment Transport Across the Continental Shelf and Lead-210 Sediment Accumulation Rates

William Wilcock

Lecture/Lab Learning Goals
- Know the terminology of and be able to sketch passive continental margins
- Differences in sedimentary processes between active and passive margins
- Know how sediments are mobilized on the continental shelf
- Understand how lead-210 dating of sediments works
- Application of lead-210 dating to determining sediment accumulation rates on the continental shelf and the interpretation of these rates - LAB

Passive Margins
Transition from continental to oceanic crust with no plate boundary.
Formerly sites of continental rifting

Terminology
Continental Shelf - Average gradient 0.1°
Shelf break at outer edge of shelf at 130-200 m depth (130 m depth = sea level at last glacial maximum)
Continental slope - Average gradient 3-6°
Continental rise (typically 1500-4000 m) - Average gradient 0.1-1°
Abyssal Plain (typically > 4000 m) - Average slope <0.1°
### Active Margins

**The Two Basic Types of Continental Margins**
- Active Margin (where subduction and volcanism occur)
- Passive Margin (adjacent to where seafloor spreading occurs)

- **Plate boundary (usually convergent)**
- **Narrower continental shelf**
- **Plate boundary can move on geological time scales - accretion of terrains, accretionary prisms**

---

### Sediment Supply to Continental Shelf
- **Rivers**
- **Glaciers**
- **Coastal Erosion**

### Sediment Transport across the Shelf

Once sediments settle on the seafloor, bottom currents are required to mobilize them.
- **Wave motions**
- **Ocean currents**

---

### Sediment Transport differences

- **Passive Margin Profile**
  - Continental Shelf
  - Continental Rise
  - Abyssal Plain
  - Mid-Ocean Ridge

- **Active Margin Profile**
  - Sediment Transport across the Shelf
  - Volcanic Arc
  - Accretionary Prism (green)
  - Mid-Ocean Ridge

Active margins - narrower shelf, typically have a higher sediment supply, earthquakes destabilize steep slopes.

---

### Sediment Mobilization - 1. Waves

- **Wave Base** = \( \frac{1}{2} L \)
- **Wave motion does not occur below wave base**

The wave base or maximum depth of wave motions is about one half the wave length.
Shallow water waves

Wave particle orbits flatten out in shallow water
Wave generated bottom motions:
• strongest during major storms (big waves)
• extend deepest when the coast experiences long wavelength swell from local or distant storms

Sediment Mobilization 2. Bottom Currents

• The wind driven ocean circulation often leads to strong ocean currents parallel to the coast.
• These interact with the seafloor along the continental shelf and upper slope.
• The currents on the continental shelf are often strongest near outer margins

Agulhas current off east coast of southern Africa. The current flows south and the contours are in units of cm/s

Sediment Distribution on the Continental shelf

Coarse grained sands - require strong currents to mobilize, often confined to shallow water where wave bottom interactions are strongest (beaches)
Fine grained muds - require weaker currents to mobilize, transported to deeper water.

Upcoming lab

In the lab following this lecture you are going to calculate a sedimentation rate for muds on the continental shelf using radioactive isotope Lead-210 and you are going to interpret a data set collected off the coast of Washington.
Radioactive decay - Basic equation

The number or atoms of an unstable isotope elements decreases with time

\[ \frac{dN}{dt} \propto N \]

- Number of atoms of an unstable isotope

\[ \frac{dN}{dt} = \lambda N \]

- radioactive decay constant is the fraction of the atoms that decay in unit time (e.g., yr\(^{-1}\))

\[ T_{1/2} = \frac{\ln 2}{\lambda} \]

- half life is the time for half the atoms to decay

Activity - Definition and equations

Activity is the number of disintegrations in unit time per unit mass (units are decays per unit time per unit mass. For \(^{210}\)Pb the usual units are dpm/g = decays per minute per gram)

\[ A = c \lambda N \]

- C - detection coefficient, a value between 0 and 1 which reflects the fraction of the disintegrations are detected (electrically or photographically)

\[ \frac{dA}{dt} = \lambda A \]

- Obtained by multiplying both sides of the middle equation on the previous slide by the constant cA

238\(^{\text{U}}\) Decay Series

\(^{210}\)Pb or Pb-210 is an isotope of lead that forms as part of a decay sequence of Uranium-238

238\(^{\text{U}}\) → 234\(^{\text{U}}\) → 230\(^{\text{Th}}\) → 226\(^{\text{Ra}}\)

- Half life 4.5 Byr
- Rocks

222\(^{\text{Rn}}\) → 210\(^{\text{Pb}}\) → 206\(^{\text{Pb}}\)

- Gas, half life 3.8 days
- Half life, 22.3 years
- Stable
**210-Pb in sediments**

Sediments contain a background level of $^{210}\text{Pb}$ that is "supported" by the decay of $^{226}\text{Ra}$ (radium is an alkali metal) which is easily eroded from rocks and incorporated into sediments. As fast as this background $^{210}\text{Pb}$ is lost by radioactive decay, new $^{210}\text{Pb}$ atoms are created by the decay of $^{226}\text{Ra}$.

Young sediments also include an excess or "unsupported" concentration of $^{210}\text{Pb}$. Decaying $^{238}\text{U}$ in continental rocks generates $^{222}\text{Rn}$ (radon is a gas) some of which escapes into the atmosphere. This $^{222}\text{Rn}$ decays to $^{210}\text{Pb}$ which is then efficiently incorporated into new sediments. This unsupported $^{210}\text{Pb}$ is not replaced as it decays since the radon that produced it is in the atmosphere. Measurements of how the excess $^{210}\text{Pb}$ decreases with depth can be used to determine rates.

**Pb-210 concentrations in sediments**

**Excess Pb-210 concentrations**

For a constant sedimentation rate, $S$ (cm/yr), we can replace the depth axis with a time axis

$$ z = St $$

$$ t = \frac{z}{S} $$

**Solving the equation - 1**

$$ - \frac{dA}{dt} = \lambda A $$

The equation relating activity to the radioactive decay constant

$$ \int_{A_1}^{A_2} - \frac{dA}{A} = \int_{t_1}^{t_2} \lambda dt $$

Integrating this with the limits of integration set by two points

$$ \left[ - \ln A \right]_{A_1}^{A_2} = \lambda \left[ t \right]_{t_1}^{t_2} $$

$$ - \ln A_2 + \ln A_1 = \ln \frac{A_1}{A_2} = \lambda (t_2 - t_1) $$

A relationship between age and activity
Solving the equation - 2

\[ \ln \frac{A_1}{A_2} = \lambda (t_2 - t_1) \]

\[ (t_2 - t_1) = \frac{(z_2 - z_1)}{S} \]

Substitute in the relationship between age and depth

\[ \ln \frac{A_1}{A_2} = \frac{\lambda (z_2 - z_1)}{S} \]

\[ S = \frac{\lambda (z_2 - z_1)}{\ln \frac{A_1}{A_2}} \]

An expression for the sedimentation rate

---

Summary - How to get a sedimentation rate

1. Identify the background ("supported") activity \( A_b \) - the value of \( A \) at larger depths where it is not changing with depth.
2. Subtract the background activity from the observed activities at shallower depths and take the natural logarithm to get \( \ln(A) = \ln(A_{\text{observed}} - A_b) \)
3. Plot depth \( z \) against \( \ln(A) \).
4. Ignore the points in the surface mixed region where \( \ln(A) \) does not change with depth.
5. Ignore points in the background region at depth \( A_{\text{observed}} = A_b \).
6. Measure the slope in the middle region (take it as a positive value).
7. Multiply the slope by the radioactive decay constant \( (\lambda = 0.0311 \text{ yr}^{-1}) \) to get the sedimentation rate.

---

Limitations

- Assumption of uniform sedimentation rates. Cannot use this technique where sedimentation rate varies with time (e.g., turbidites).
- Assumption of uniform initial and background Pb-210 concentrations (reasonable if composition is constant).