Havet at Stockholms Universitet

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1 Chapter 1

1.1 Oceans

Pacific Ocean:

- largest ocean
- more than hald of ocean surface on Earth
- over one third of Earth's entire surface
- deepest ocean

Atlantic Ocean:

- about half the size of Pacific Ocean
- separates the Old World (Europe, Asia, Africa) from the New World (North and South America)
- named after Atlas, one of the Titans in Greek mythology

Indian Ocean:

- slighty smaller than Atlantic Ocean
- about same average depth as Atlantic
- mostly in the Southern Hemisphere

Arctic Ocean:

- about 7% size of the Pacific Ocean
- only a bit over one-quarter as deep as the rest of the oceans
- has a permanent layer of sea ice at the surface, but the ice is only a few meters thick

Southern or Antarctic Ocean:

- it is really the portions of Pacific, Atlantic and Indian oceans south of about 50 degrees south latitude

The average depth of the world's oceans is 3682 meters. The deepest depth in the oceans (the Challenger Deep region of the Mariana Trench) is 11022 meters below sea level.

The average height of the continents is only 840 meters.

1.2 History of Ocean exploration

- Pytheas in 325 B.C. sailed northward using a simple method for determining latitude in the Northern Hemisphere
- Eratosthenes used the shadow of a stick in a hole in the ground and elementary geometry to determine Earth's circumference to be 40000 km
- Claudius Ptolemy produced a map of the world in about 150 A.D. that represented the extent of Roman knowledge at that time
- late in the 10th century the Vikings colonized Iceland
- in about 981 A.D. Erik "the Red" Throvaldson sailed westward from Iceland and discovered Greenland
- Leif Eriksson, son of Erik the Red, found Vinland (Newfoundland, Canada) and spent the winter there
- 1492 to 1522 is known in Europe as *Age of Discovery*. Southern Europeans explored the continents of South and North America then.
- Captain James Cook blah blah

1.3 What is Oceanography

It is an **interdisciplinary science**

Geology:

- sea floor tectonics
- coastal processes
- sediments
- hydrologic cycle

Geography:

- wind belts
- weather
- coastal landforms
- world climate

Biology:

- fisheries
- ecological surveys
- microbiology
- marine adaptations

Chemistry:

- dissolved components
- temperature dependence
- stratification/density
- chemical tracers

Physics:

- currents
- waves
- sonar
- thermal properties of water

Astronomy:

- tidal forces
- oceans on other planets
- origin of water
- origin of life

Four main disciplines of oceanography:

- **geological** oceanography
- **chemical** oceanography
- **physical** oceanography
- **biological** oceanography

1.4 Density stratification

- once Earth became a ball of hot liquid rock, the elements were able to segregate according to their densities in a process called density stratification
- highest-density materials (primarily iron and nickel) concentrated in the core
- progressively lower-density components (primarily rocky material) formed concentric spheres around the core

Earth consists of 3 chemical layers:

- crust: about 30km deep
- mantle: about 2885km deep
- core: to the center of the Earth at 6371km deep

Earth consists of 5 physical layers:

- inner core: rigid and does not flow (because of increased pressure at the center of Earth)
- outer core: liquid and capable of flowing
- mesosphere: extends from 700km to 2885km deep, which corresponds to the middle and lower mantle. It is rigid due to increased pressure at these depths.
- asthenosphere: plastic (flows under force). Extends from about 100km to 700km deep. Hot enough to partially melt portions of most rocks. Corresponds to the base of the upper mantle.
- litosphere: cool rigid outermost layer. Avg depth 100km. Includes the crust plus the topmost portion of the mantle.

1.5 Oceanic vs continental crust

Oceanic crust

- Oceanic crust underlies the ocean basins and is composed of basalt and has 3x higher density than water.
- The avg thickness of the oceanic crust is about 8km.
- Basalt originates as molten magma beneath Earth's crust (typically from the mantle), some of which comes to surface during underwater sea floor eruptions.

Continental crust

- Composed mostly of lower-density and lighter-colored igneous rock granite
- It has density of about 2.7g per cubic cm
- The avg thickness of the continental crust is about 35km, up to 60km beneath the highest mountain ranges.
- Most granite originates beneath the surface as molten magma that cools and hardens within Earth's crust.

No matter which type of crust is at the surface, it is all part of the litosphere.

1.6 Asthenosphere

- Relatively hot, plastic region beneath the litosphere.
- Extends from the base of the litosphere to about 700km.
- Entirely contained within the upper mantle.
- Can deform without fracturing if a force is applied slowly.
- High viscosity (stickiness, resistance to flow).

1.7 Isostatic adjustment

- The vertical movement of crust is the result of the buoyancy of Earth's lithospere as it floats on the denser, plastic-like asthenosphere below.
- For example, a heavier ship with more cargo will sit lower in the water than a lighter ship.
- Similarly, both continental and oceanic crust float on the denser mantle beneath and get adjusted.
- **Isostatic rebound** – example is how the sea floor is rising in Scandinavia after the last ice age

1.8 How were Earth's atmosphere and oceans formed?

- Early in Earth's history, volcanic activity released large amounts of water vapour into the atmosphere.
- Water vapour condensed into clouds.
- Liquid water fell to Earth's surface where it accumulated in low areas and over time formed the oceans.

Atmosphere:

- Earth's initial atmosphere consisted of leftover gases from the nebula.
- **Outgassing** – expelling of gasses from inside Earth

Oceans:

- Since outgassing releases mostly water vapour, this was the primary source of water on Earth, including supplying oceans with water.
- Water could have also been supplied by space debris leftovers (from the forming of the solar system) bombarding the Earth.
- Development of ocean salinity: early atmosphere had a lot of carbon and sulfur dioxide content which created very acidic rain, capable of dissolving greater amounts of minerals in the crust than occurs today.

1.9 Did life begin in the oceans?

- Earliest-known life-forms were primitive bacteria that lived in sea floor rocks about 3.5 Bya.
- Oxygen is essential to human life for 2 reasons:
  - Our bodies need oxygen to "burn" (oxidize) food, releasing energy to our cells.
  - Oxygen in the upper atmosphere in the form of ozone protects the surface of Earth from most of the Sun's harmful ultraviolet radiation.

1.10 Glossary of terms

- **oceans** – the entire body of saltwater that covers 70% of Earth's surface
- **nebula** – a huge cloud of gas and space dust
- **nebular hypothesis** – all bodies in the solar system formed from an enormous cloud composed mostly of hydrogen and helium with only a small percentage of heavy elements
- **Pacific Ocean** – The ocean located between Australia, Asia, North America, and South America; the largest ocean in the world.
- **Atlantic Ocean** – The ocean located between South America, North America, Europe, and Africa; the second largest ocean in the world.
- **Indian Ocean** – The ocean located between Africa, India, and Australia; it exists mostly in the Southern Hemisphere and is the third largest ocean in the world.
- **Arctic Ocean** – The ocean located in the Northern Hemisphere polar region; the smallest ocean in the world.
- **Southern Ocean / Antarctic Ocean** – The ocean that surrounds the continent of Antarctica and is located south of about 50 degrees south latitude.
- **Latitude** – Location on Earth's surface based on angular distance north or south of the equator. Equator = 0 degrees. North Pole = 90 degrees north. South Pole = 90 degrees south.
- **Longitude** – Location on Earth's surface based on angular distance east or west of the Prime (Greenwhich) Meridian (0 degrees longitude). 180 degrees longitude is the International Date Line.
- **nebular hypothesis** – A model that describes the formation of the solar system by contraction of a nebula.
- **protoplanet** – Any planet that is in its early stages of development.
- **thermonuclear fusion** – A high temperature process in which hydrogen atoms are converted to helium atoms, thereby releasing large amounts of energy.
- **density stratification** – A layering based on density, where the highest density material occupies the lowest space.
- **crust** – (1) The uppermost outer layer of Earth's structure that is composed of basaltic oceanic crust and granitic continental crust. The average thickness of the crust ranges from 8km beneath the ocean to 35km beneath the continents. (2) A hard covering or surface layer of hydrogenous sediment.
- **mantle** – (1) The zone between the core and crust of Earth; rich in ferromagnesian minerals. (2) In pelecypods, the portion of the body that secretes shell material.
- **core** – (1) The deep, central layer of Earth, composed primarily of iron and nickel. It is subdivided into a liquid outer core 2270km thick and solid inner core with a radius of 1216km. (2) A cylinder of sediment and/or rock material usually obtained by drilling.
- **mesosphere** – The middle region of Earth below the asthenosphere and above the core.
- **asthenosphere** – A plastic layer in the upper mantle 80 to 200km deep that may allow lateral movement of litospheric plates and isostatic adjustments.
- **lithosphere** – The outer layer of Earth's structure, including the crust and the upper mantle to a depth of about 200km. Lithospheric plates are the major components involved
- **oceanic crust** – A mass of rock with a basaltic composition that is about 5km thick.
- **basalt** – A dark-colored volcanic rock characteristic of the ocean crust. Contains minerals with relatively high iron and magnesium content.
- **granite** – A light-colored igneous rock characteristic of the continental crust that is rich in nonferromagnesian minerals such as feldspar and quartz.
- **viscosity** – A property of a substance to offer resistance to flow caused by internal friction.
- **isostatic adjustment** – The adjustment of crustal material due to isostasy.
- **isostatic rebound** – The upward movement of crustal material due to isostasy.
- **outgassing** – The process by which gases are removed from within the Earth's interior.
- **heterotrophs** – Animals and bacteria that depend on the organic compounds produced by other organisms as food. Organisms not capable of producing their own food by photosynthesis.
- **autotrophs** – Algae, plants, and bacteria that can synthesize organic compounds from inorganic nutrients.

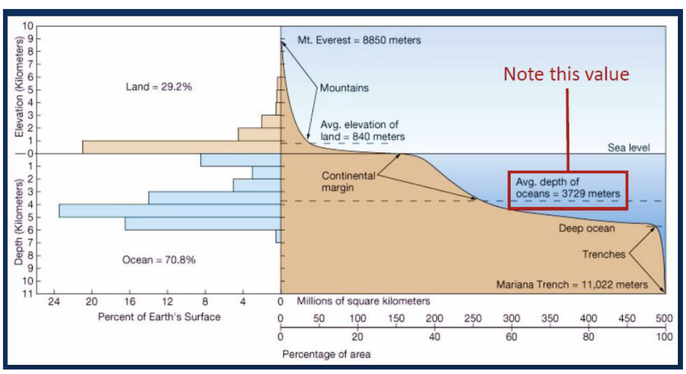
- **anaerobic** – Requiring or occuring in the absence of free oxygen (O_2).
- **chemosynthesis** – A process by which bacteria or archaea synthesize organic molecules from inorganic nutrients using chemical energy released from the bonds of a chemical compound (such as hydrogen sulfide) by oxidation.
- **chlorophyll** – A group of green pigments that make it possible for plants to carry on photosynthesis.

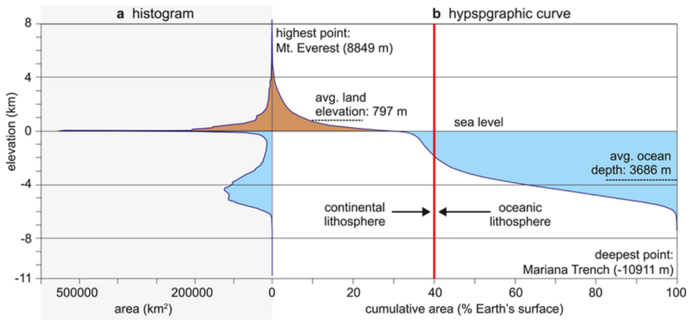
2 Lecture 1: Introduction to Earth, Richard Gyllencreutz

Icebreaker Oden:

- The currents around Antarctica are the strongest currents in the world.
- We've had ice sheets on Antarctica for about 34 Ma.
- The hypsographic curve
- Hypsometry = area vs. depth/height
- Shows the percentage of Earth's surface within a certain range of land height or sea depth.
- You can use the hypsographic curve to calculate the area of Earth's surface over a particular height or elevation range.
- For example, about 23% of the surface is 4km to 5km below sea level.

2.1 The hypographic curve





- Solar system – one star, 4 small rocky planets, 4 gas giants.
- The Asteroid belt consists of rock material hindered to become planets because of Jupiter's strong gravity. The objects are about 1 mil km apart, and their total mass is about 3% of the Moon's.
- The Asteroid belt is between the 4 rocky planets and the gas giants.

The Earth's internal structure:

- Crust, solid, 0 to 7-70km
- Mantle, solid but malleable, to 2900km
- Outer core, liquid, to 5100km
- Inner core, solid, to 6317km

The magnetic field:

- The core is mostly iron and nickel.
- The magnetic field is formed by convection currents in the liquid outer core. Earth's rotation → aligns the currents and magnetic field roughly with the axis.
- Sometimes, the magnetic north and south pole switches rapidly → magnetic pole reversals preserved in rock/sediments → magnetic time scale.
- Highly irregular – up to millions of years between.

2.2 How do we know the Earth's interior?

- Seismic measurements
- Nebular hypothesis
- Laboratory experiments
- Studies of meteorites

2.2.1 Earthquakes tell us the Earth's inner structure

Earthquakes can travel as P-waves, S-waves and surface waves. Only P-waves can travel through fluids. Sound waves are P-waves.

How do we know the inside of Earth? **Seismic waves**. Knowledge about Earth's interior is based on many sources of information, but the most important observations come from **seismographs** (which produce **seismograms**).

Seismographs in different locations show when and where on Earth s-waves and p-waves are registered from earthquakes (or nuclear bombs).

P-waves are refracted at boundaries between materials with different wave velocity (refraction by Snell's Law, like for all waves).

2.2.2 Nebular hypothesis – collapsing cloud of gas and dust

- Stars are formed in nebulas (clouds of gas and dust) that contracts if it contains ¿80 jupiter masses → gravity overcomes the gas pressure. The central region → the start. The rest o the gas and dust → the planets.

2.2.3 How do we know about the Earth's interior? Laboratory experiments

Lab experiments with diamond anvil cell (DAC) exposes tiny samples to pressures up to 770 GPa, can be heated by laser to ¿ 5k Celsius, and show how various materials behave under the extreme conditions inside planets. Because diamond is transparent to various types of radiation, the sample can be observed throughout the experiment.

2.2.4 How do we know about the Earth's interior? Meteorite studies

The most common are stony meteorites (chondrites and achondrites), iron-stone meteorites, and iron meteorites. Chondrites contain tiny mineral particles (chondrules), are about 4.5 Ba old and are thought to represent the original composition that the stony planets were formed of.

2.3 Composition of the Earth

2.3.1 Crust

- Oxygen: 46%
- Silicon: 28%
- Oxygen: 46%
- Oxygen: 46%

2.3.2 Mantle

- Oxygen: 44%
- Silicon: 21%
- Magnesium: 22.8%
- Iron: 6.3%
- Calcium: 2.5%

2.3.3 Outer core

- Iron: 85%
- Oxygen: 5%
- Sulfur: 5%
- Nickel: 5%

2.3.4 Inner core

- Iron: 94%
- Nickel: 5%

2.4 How were the oceans formed?

- The primary atmosphere consisted of gases from the planetary accretion – H_2, CH_4, NH_3 (common on the gas giants)
- Soon, volcanoes emitted H_2O, CO_2, N_2, and some CO, H_2.
- Impacts from comets probably also contributed with H_2O and CO_2.
- The Earth had cooled enough for liquid water to collect after about 500 Ma.
- The ocean basins are formed by plate tectonics and density differences.
- Ocean crust is thinner, denser, and "floats" on a deeper level than continental crust on the mantle.
- Ocean crust is formed at mid-ocean ridges and destroyed in subduction zones, and can never become thick. The oldest ocean crust is only about 200 Ma.

2.5 Different plate margins, different results

- Convergent plate margin Ocean – Ocean
- Divergent plate margin
- Ocean – Continent
- Convergent plate margins
- Continent – Continent

2.6 International Hydrographic Organization (IHO)

- Established in 1921 as the International Hydrographic Bureau (IHB)
- In August 2024 the IHO comprised 100 Member States.
- Decided the limits of oceans and seas. Hasn't changed since 1953.

2.7 What is a "sea"?

- Composed of salt water, with some exceptions
- Smaller and shallower than an ocean
- To some extent enclosed by land
- Connected to the ocean

2.8 The bathymetry of the world ocean floor

- Lead lines (depth)
- Singe beam echo sounder (depth) – one depth per ping
- Multibeam echo sounder (depth, seafloor morphology and characteristics). Often called "Swath bathymetry".

- Marie Tharp

2.9 The basic principle of echo sounding

- A sound pulse is sent through the water column from a transmitter (Tx)
- The pulse echoes (is reflected) from the seafloor and is received at a receiver (Rx). In simple systems, the Tx and Rx are one and the same unit.
- The two-way travel time (twt) is registered from when the pulse was transmitted until it is received.

2.10 The first bathymetric maps

- Marie Tharp was the first to identify a central valley along the mid-ocean ridge – a major indication that plates are diverging there. Fundamental theory for the plate tectonic theory!

2.11 We have only mapped 25% of the world ocean

75% of the oceans floor is only mapped using satellite measurements of sea surface and gravity.

Sea mount attract water $\rightarrow$ sloping sea surface $\rightarrow$ deflection of gravity.

A challenge with existing mapping technologies is the trade-off between coverage and resolution.

3 Chapter 2

3.1 Glossary of terms

- **plate tectonics** –
- **continental drift** –
- **Pangaea** –
- **Panthalassa** –
- **Tethys Sea** –
- **ice age** –
- **Mesosaurus** –
- **ingeous rocks** –
- **magma** –
- **lava** –
- **magnetite** –
- **sedimentary rock** –
- **paleomagnetism** –
- **magnetic dip** –
- **seafloor spreading** –
- **mid-ocean ridge** –
- **convection cells** –
- **spreading center** –
- **ocean trenches** –
- **subduction** –
- **subduction zone** –
- **heat flow** –
- **litosphere** –
- **asthenosphere** –
- **divergent boundaries** –
- **convergent boundaries** –
- **transform boundaries** –
- **rift valley** –
- **rifting** –
- **subsidence** –
- **oceanic rises** –
- **oceanic rdiges** –
- **Mid-Atlantic Ridge** –
- **East Pacific Rise** –
- **seismic moment magnitude** –
- **volcanic arc** –
- **continental arc** –
- **island arc** –
- **transform fault** –
- **hotspot** –
- **mantle plume** –
- **nematath** –
- **seamounts** –
- **tablemounts, guyots** –
- **coral reef** –
- **fringing reef** –
- **barrier reef** –
- **atoll** –
- **paleogeography** –
- **continental accretion** –
- **terranes** –
- **Wilson cycle** –

4 Chapter 3

- **bathymetry** –
- **sounding** –
- **fathom** –

- **echo sounder** –
- **ping** –
- **precision depth recorder** –
- **sonar** –
- **seabeam** –
- **seamount** –
- **seismic reflection profiles** –
- **continental margins** –
- **deep-ocean basins** –
- **passive margins** –
- **active margins** –
- **convergent active margins** –
- **transform active margins** –
- **continental shelf** –
- **shelf break** –
- **continental borderland** –
- **continental slope** –
- **submarine canyons** –
- **turbidity currents** –
- **continental rise** –
- **graded bedding** –
- **turbidite deposit** –
- **deep-sea fans** –
- **submarine fans** –
- **abyssal plains** –
- **suspension settling** –
- **abyssal hills** –
- **seaknolls** –
- **abyssal hill provinces** –
- **ocean trench** –
- **pillow lava** –
- **pillow basalt** –
- **hydrothermal vent** –
- **fracture zones** –

4.1 Lecture 2: Chemistry of the oceans, the basics

4.2 Red Shift

1929 Edwin Hubble discovered that the distance to galaxies and their velocity were related.

4.3 Big Bang Nucleosynthesis

Alpher, Bethe and Gamov

- Made first calculations of the origin of elements in late 1940s
- Initially protons, neutrons and electrons. After a short time, they were combined to hydrogen, helium and small amount of Lithium and ^{7}Be through fusion
- Other elements need stars and supernovas

4.4 Where do the elements come from

- In 1920 Arthur Eddington suggested that nuclear fusion is the fuel in stars and possibly the heavier elements are formed in stars
- It was not until 1957 that there was an understanding where the elements come from when a paper by Burbidge et al was published. The man behind the paper was Fred Hoyle.

4.5 Elemental abundance in the solar system

Fusion in stars, exploding stars are the source for the elements. S and R process need free neutrons in order to form the heaviest elements.

4.6 What is the Sun made of, a star close to us

- Until the 1920s the Sun was thought to be a very hot rock consisting of mostly iron
- Cecilia Payne showed in 1925 that the Sun was mainly composed of hydrogen and helium. Nobody believed her at first, but this was later accepted in 1929 and shown in another way by the person that did not believe her. All stars are mainly composed of hydrogen and helium, where hydrogen is fused to helium releasing energy.

4.7 Formation of the solar system and Earth

- Earth was formed 4.6B years ago from a cloud of gas and dust (a nebula) where the elements came from stars (and supernovas) in our part of space
- Planet properties reflect their proximity to the early sun
- Some planets have experienced major perturbations and/or collisions (Venus, Earth)
- Comets and asteroids are debris left over from solar system formation

4.8 How water came to Earth

Earth was from start a hot rock, which means that condensation of water at formation is not possible (the Earth was too hot).

Theories about water on Earth:

1. The proto-Sun emitted enormous amounts of water to space that existed as clouds around the sun and was incorporated into asteroids and comets
2. Another theory is that water comes from minerals and the collision with Theia that created our moon

4.9 Composition of ocean/atmosphere

The chemical composition of oceans and atmosphere can be seen as a result of a reaction:

Minerals + volcanic gases = atmosphere + sea water + sediment

4.10 Thermohaline circulation (thermo = temperature, haline = salt)

Driven by global differences in density gradients, where colder and saltier waters have higher densities than warmer and less salty waters.

4.11 Lysocline and CCD

Lysocline = where the rate of dissolution starts to increase rapidly

CCD = Carbon Compensation Depth, where the rate of dissolution equals production

Solubility of carbonates depends on:

- Ion concentrations
- Saturation degree
- Pressure: solubility increase with pressure
- Temperature: solubility increase with decreasing temperature
- CO_2 pressure: solubility increase with increasing CO_2

5 Lecture 3: Plate Tectonics and the Ocean Floor

5.1 Plate tectonics: the history

- Alfred Wegener (1880-1930)
- German meteorologist and geophysist
- First with the idea of moving continents
- Published *The origin of the continents and oceans* 1915
- He saw the continents as drifting: *Continental drift*

5.2 Supporting evidence for plate tectonics

1. **Matching coast lines**. Wegener's fit (according to coastlines) was imperfect, but if you use 2000m isobaths it's much better.

5.3 Critique to the continental drift theory

- Wegener had suggested that the continents plowed through the ocean basins, but how is that possible?
- The force was Earth's gravitational attraction from the equator bulge and tidal forces from the Sun and Moon. But the forces were shown not to be enough.

5.4 How does a rock become magnetic?

- Magnetism in a rock only occurs when a lava has cooled off enough for the atoms to be able to arrange for the magnetic field. The temperature at which it occurs is called the *Curie temperature*.
- When solidifying a lava, the direction of the Earth's magnetic field is locked in the rock, that is the magnetic domains are arranged according to the Earth's current polarity.

Vine-Matthews-Morley Hypothesis

5.5 Seafloor age

The oldest oceanic crust is 280 Ma. Crust disappears in the subduction zones.

5.6 The bathymetry of the World ocean floor

Bruce Heezen (1924-1977, geologist) and Marie Tharp (1920-2006, geographer).

First physiographic map of the Atlantic published by Heezen and Tharp 1957

5.7 Harry Hess put it all together

- Hess realized that seafloor's thin sediment cover (relative to the sediment cover on the continents) meant that the ocean floors were much younger than the continents.
- As the seabed sediment cover thinned out toward the mid-oceanic ridges, these were younger than the deeper deposits of the oceans.
- He published an article *History of ocean basins* (1962) in which he included the idea of seafloor spreading.

5.8 Summary

- 1957: Heezen and Tharp's physiographic map of the Atlantic show that spreading ridges exist
- 1962: Hess provided a theory for seafloor spreading, including how it could work with mantle convection
- Vine-Matthew-Moreley hypothesis explains how the magnetic field changes over time are encoded in seafloor

5.9 Passive vs active continental margins

Passive margin: no active plate boundary

Active margin: steep slope, trench, convergent, subduction

5.10 Submarine canyons and deep-sea fans

- **Turbidity currents** (mixtures of sediment and water) carve **submarine canyons** into the slope and shelf.
- Debris from turbidity currents creates **graded bedding** deposits and **deep-sea fans**.

5.11 Abyssal plains

- Deep, flat areas formed by suspension settling of fine grained sediment.
- Volcanic peaks poke through the sediment
  - Abyssal hills
  - Seamounts
  - Tablemounts (guyots)

5.12 Ocean trenches

- Deepest parts of the ocean
- Formed by plate convergence (subduction zones – destruction of old oceanic crust)
- Most trenches are in the Pacific Ocean
- Associated with volcanic arcs
  - Island arc
  - Continental arc

6 Chapter 4

6.1 Neritic and pelagic deposits

Marine sedimentary deposits can be categorized as either neritic or pelagic.

Neritic deposits (*neritos* – of the coast) are found on continental shelves and in shallow water near islands; these deposits are generally coarse grained. Pelagic deposits (*pelagios* – of the sea) are found in the deep ocean basins and are typically fine grained.

6.2 Types of sediment

6.2.1 Lithogenous

- originates from the weathering of rocks
- the greatest quantity of lithogenous material is found around the margins of the continents, where it is constantly moved by high-energy currents along the shoreline and in deeper turbidity currents
- the majority of lithogenous deposits – such as beach sands – are composed primarily of quartz
- lithogenous sediment dominates most neritic deposits
- beach deposits – beach materials are composed mostly of quartz-rich sand that is washed down to the coast by rivers but can also be composed of wide variety of sizes and compositions
- continental shelf deposits – at the end of the last ice age (10ka) glaciers melted and sea level rose; currently rivers typically drop sediment in their drowned river mouths, but in geologic past it would travel further to the continental shelf
- turbidite deposits – turbidity currents are underwater avalanches that periodically move down the continental slopes and carve submarine canyons; they also carry a vast number of neritic material; this material spreads out as deep-sea fans, comprises the continental rise, and gradually thins toward the abyssal plains
- glacial deposits – poorly sorted deposits containing particles ranging from boulders to clays, found in high-latitude portions of the continental shelf
- most pelagic deposits are composed of fine-grained material that accumulates slowly on the deep-ocean floor; pelagic lithogenous sediment includes particles that have come from volcanic eruptions, windblown dust, and fine material that is carried by deep-ocean currents
- abyssal clay – composed of at least 70% (by weight) fine, clay-sized particles from the continents; because they contain oxidized iron, they are commonly red-brown or buff in color and sometimes referred to as red clays

6.2.2 Biogenous

- from hard parts of living organisms (shells, bones, and teeth)
- can be classified as either macroscopic or microscopic
- macroscopic biogenous sediment is large enough to be seen without a microscope and includes shells, bones, and teeth of large organisms; relatively rare
- microscopic biogenous sediment contains particles so small they can only be seen with a microscope; microscopic organisms produce tiny shells called tests (*testa* – shell) that begin to sink after the organisms die and continually rain down in great numbers onto the ocean floor
- the microscopic tests accumulate on the deep-ocean floor and form deposits called ooze (*wose* – juice)
- biogenous sediment is mostly created by algae and protozoans
- the two most common chemical compounds in biogenous sediment are calcium carbonate ($CaCO_3$, which forms calcite) and silica (SiO_2)
- two significant sources of calcium carbonate biogenous ooze are the foraminifers (*foramen* – an opening) and microscopic algae called coccolithophores
- when the organism dies, the individual plates (called coccoliths) disaggregate and can accumulate on the ocean floor as coccolith-rich ooze; this ooze then lithifies as chalk
- the White Cliffs of southern England are composed of hardened coccolith-rich calcium carbonate ooze, which was deposited on the ocean floor and has been uplifted onto land
- biogenous sediment is one of the most common types of pelagic deposits
- biogenous carbonate deposits are common in some areas
- most limestones contain fossil marine shells, suggesting a biogenous origin, while other carbonate-containing rocks appear to have been formed directly from seawater without the help of any marine organism
- ancient marine carbonate deposits constitute 2% of Earth's crust and 25% of all sedimentary rocks on Earth

- stromatolites – cyanobacteria produce these deposits by trapping fine sediment in mucous mats; other types of algae produce long filaments that bind carbonate particles together
- microscopic biogenous sediment (ooze) is common on the deep-ocean floor because there is so little lithogenous sediment deposited at great distances from the continents that could dilute the biogenous material
- calcareous ooze can deposit on top of the mid-ocean ridge and then as it spreads and goes below CCD it is already covered and protected by abyssal clay

6.2.3 Hydrogenous

- chemical reactions within seawater cause certain minerals to come out of solution (to precipitate)
- precipitation usually occurs when there is a change in conditions such as in temperature or pressure
- manganese nodules are rounded, hard lumps of manganese, iron and other metals typically 5 centimeters in diameter up to a maximum of about 20 centimeters
- when cut in half, they often reveal a layered structure formed by precipitation around a central nucleation object
- the formation of manganese nodules requires extremely low rates of lithogenous or biogenous input so that the nodules are not buried
-

6.2.4 Cosmogenous

6.3 Glossary of terms

- **sediments** –
- **suspension settling** –
- **texture** –
- **core** –
- **rotary drilling** –
- **paleoceanography** – the study of how the ocean, atmosphere, and land have interacted in the past to produce changes in ocean chemistry, circulation, biology, and climate
- **lithogenous sediment** –
- **terrigenous sediment** –
- **biogenous sediment** –
- **hydrogenous sediment** –
- **cosmogenous sediment** –
- **quartz** –
- **grain size** –
- **sorting** –
- **neritic deposits** –
- **pelagic deposits** –
- **turbidity currents** –
- **ice rafting** –
- **abyssal clay** –
- **tests** –
- **ooze** –
- **protozoans** –
- **calcium carbonate** –
- **silica** –
- **diatom** –
- **radiolarian** –
- **plankton** –
- **diatomaceous earth** –
- **foraminifers** –
- **coccolithophores** –
- **nannoplankton** –
- **chalk** –
- **calcareous ooze** –
- **limestone** –
- **coccolith** –
- **carbonate** –
- **stromatolites** –
- **lysocline** –
- **calcite compensation depth (CCD)** –
- **upwelling** –
- **precipitate** –
- **maganese nodules** –
- **phosphates** –
- **aragonite** –
- **oolites** –
- **metal sulfides** –
- **evaporite materials** –
- **spherules** –
- **meteor** –
- **tektiles** –
- **meteorite** –
- **petroleum** –
- **gas hydrates** –
- **methane hydrates** –
- **salt deposits** –
- **phosphorite** –

- **crusts** –

7 Lecture 4: Marine Sediments

7.1 Marine sediments

1. Sediment layers represent a record of Earth history, including:
   - Movement of tectonic plates
   - Past changes in climate
   - Ancient ocean circulation patterns
   - Cataclysmic events (meteorites, tsunamis, volcanic eruptions)
2. Are a critical and active component of global biochemical cycles
3. Marine sediments contain valuable economic resources
4. Contain an enormous amount of biomass – *A frontier area of microbiological life* and a critical component of the global carbon cycle

7.2 Sampling the seafloor

- Coring
- Coring tools are simple in design: a long metal pipe, with a very heavy weight 100-200kg, that falls down until it hits the seafloor
- Other tools for sampling the seafloor

In a neritic deposit you will recover 10ka of Earth's history from 10m long sediment core.

In a Pelagic deposit, you can capture over 1Ma of Earth's history from 10m long sediment core.

7.3 Scientific drilling vs seabed coring

- A pipe is lowered to the bottom of the sea
- Inside of the pipe is a wire with a drill at the end

7.4 Four main types of sediment

- **Lithogenous (terrigenous)** – composed of fragments of pre-existing rock material
- **Biogenous** – composed of hard remains of once-living organisms
- **Hydrogenous** – formed when dissolved materials come out of solution (precipitate)
- **Cosmogenous** – derived from outer space

7.5 Lithogenous sediment texture

- High energy $\longrightarrow$ low energy
- Bach to shallow marine, transition to deep marine

7.6 Water-river transport and run-off

In addition to sediment, the dissolved load is also an important contributor to deep-sea sedimentation. It contains PO_4, NO_3-, and other nutrients needed for plant growth, such as Ca+, HCO_3-, and H_4SiO_4, from which pelagic organisms build their shells and skeletons.

7.7 River transport and run-off

Operates across the globe, from equatorial to polar regions.

7.8 Windblown sediment

Eolian (wind blown) sediment can be traced by looking at the quartz concentration in some marine sediments.

Accumulation rates of windblown sediments in the deep sea are typically up to a few mm/1000 years.

7.9 Ice – glaciers (icebergs) and sea ice

They can carry coarse-grained material very far out to the sea.

7.10 Turbidity currents and mass transport deposits

Graded bedding: As the turbidity current slows, larger grains settle first, followed by progressively finer grains.

7.11 Biogenous: photosynthetic phytoplankton

Phytoplankton blooms in the Barents Sea, off the northern coast of Norway

7.12 Origin and composition of biogenous sediment

- Organisms that produce hard parts die
- Material rains down on the ocean floor and accumulates as:
  - Microscopic tests (shells)
  - If sediment is made of at least 30% shell material, it is called biogenous ooze
- Microscopic biogenous shells are composed of 2 main chemical compounds:
  - Silica (SiO_2): Diatoms (algae – plants), Radiolarian (protozoan – animals)
  - Calcium carbonate or calcite ($CaCO_3$): Coccolithophores (algae – plants), Foraminifers (protozoan – animals)

7.13 Lithified biogenous sediment

When biogenous ooze hardens and lithifies, it can form: Diatomaceous earth (if composed of diatom-rich ooze) or Chalk (if composed of coccolith-rich ooze).

7.14 Distribution of Biogenous sediment

- Most biogenous ooze is found as pelagic (open ocean) deposits
- Factors affecting the distribution of biogenous ooze:
  - Productivity (amount of organisms living in surface waters)
  - Destruction (dissolving at depth)
  - Dilution (mixing with lithogenous clays)
- Productivity is usually nutrient limited and is overcome in (1) areas where lithogenous sediment is delivered and (2) regions of upwelling

7.15 Distribution of siliceous ooze

Silica is generally undersaturated in seawater, so silicate shells steadily dissolve in the water column and at the seafloor.

7.16 Distribution of carbonate ooze

Calcite compensation depth (CCD) is the depth in the oceans below which the rate of supply of calcite (calcium carbonate) lags behind the rate of dissolution in the water column.

Calcite dissolves beneath the calcite compensation depth (CCD) at about 4.5km average depth.

The CCD is influenced by pressure, temperature, amount of CO_2 dissolved in sewater, and pH water. Therefore it varies in different parts of the ocean.

7.17 Distribution of carbonate sediment

Mostly around shallow seafloor – around mid-ocean ridges.

7.18 Pelagic clays – 'red clays'

Slowly accumulating 'red clays' are found in the large ocean gyres, where little productivity occurs, and where sediments are mainly fine grained terrigenous material carried by wind.

7.19 Distribution of sediment

Distribution of sediment

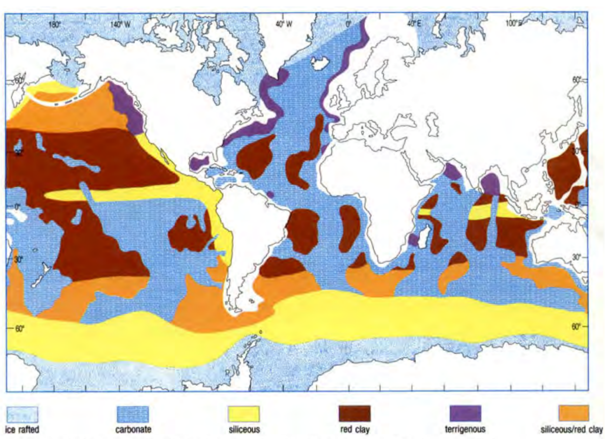


Figure 1.4 Distribution of dominant sediment types on the floor of the present-day oceans. Note that red clays are also terrigenous sediments.

8 Chapter 6: Air-Sea Interaction

8.1 Glossary of terms

- **plane of the ecliptic** – the surface connecting all points of Earth's orbit
- **vernal equinox** – the passage of Sun across the equator as it moves from the Southern Hemisphere into the Northern Hemisphere, approximately March 21. During this time, all places in the world experience equal lengths of night and day. Also known as the spring equinox.
- **summer solstice** – in the Northern Hemishpere, it is the instant when the Sun moves north to the Tropic of Cancer before changing direction and moving southward toward the equator approximately June 21.
- **Tropic of Cancer** – the latitude 23.5 degrees north, which is the furthest location north that receives vertical rays of the sun.
- **autumnal equinox** – the passage of Sun across the equator as it moves from the Northern Hemisphere, approximately September 23. During this time, all places in the world experience equal lengths of night and day. Also called fall equinox.
- **winter solstice** – the instant the southward-moving Sun reaches the Tropic of Cancer before changing firection and moving north back toward the equator, approximately December 21.
- **Tropic of Capricorn** – the latitude 23.5 degrees south which is the furthest location south that receives vertical rays of the Sun.
- **declination** – the angular distance of the Sun or Moon above or below the plane of Earth's equator
- **tropics** – the region of Earth's surface lying between the Tropic of Cancer and the Tropic of Capricorn. Also known as the Torrid Zone.
- **Arctic Circle** – the latitude 66.5 degrees north
- **Antarctic Circle** – the latitude 66.5 degrees south
- **albedo** – the fraction of incident electromagnetic radiation reflected by a surface
- **troposphere** – the lowermost portion of the atmosphere which extends from Earth's surface to 12 kilometer. It is where all the weather is produced.
- **convection cell** – a circular-moving loop of matter involved in convective movement
- **wind** – the movement of air, usually as a result of pressure differences
- **Coriolis effect** – an apparent force resulting from Earth's rotation that causes particles in motion to be deflected to the right in the Northern Hemisphere and to the eft in the Southern Hemisphere
- **Hadley cells** – the large atmospheric circulation cell that occurs between the equator and 30% latitude in each hemisphere

- **Ferrel cell** – the large atmospheric circulation cell that occurs between 30 and 60 degrees latitude in each hemisphere
- **polar cell** – the large atmospheric circulation cell that occurs between 60 and 90 degrees latitude in each hemisphere
- **subtropical highs** – a region of high atmospheric pressure located at about 30 degrees latitude
- **polar highs** – the region of high atmospheric pressure that occurs at the poles in both hemispheres
- **equatorial flow** –
- **subpolar flow** –
- **trade winds** – a global wind belt that moves from a subtropical high-pressure belt at about 30 deg north or south latitude toward the equatorial region. These winds move from a northeasterly direction in the NH and from a southeasterly direction in the SH.
- **prevailing westerly wind belts** – a global wind belt that moves from a subtropical high-pressure belt at about 30 degrees north or south latitude toward the polar front at about 60 degrees north or south latitude. These winds move from a southwesterly direction in the NH and from a northwesterly direction in the SH.
- **polar easterly wind belts** –
- **doldrum** –
- **Intertropical Convergence Zone (ITCZ)** –
- **horse latitudes** –
- **polar front** –
- **weather** –
- **climate** –
- **cyclonic flow** –
- **anticyclonic flow** –
- **sea breezes** –
- **land breezez** –
- **storms** –
- **air masses** –
- **warm front** –
- **cold front** –
- **jet stream** –
- **tropical cyclone** –
- **hurricane** –
- **cyclone** –
- **typhoon** –
- **Saffir-Simpson scale** –
- **eye of the hurricane** –
- **storm surge** –
- **equatorial** –
- **tropical** –
- **subtropical** –
- **temperate** –
- **subpolar** –
- **sea ice** –
- **iceberg** –
- **pancake ice** –
- **ice floes** –
- **pressure ridges** –
- **shelf ice** –

9 Chapter 7

10 Lecture 5.1: Air-Sea interaction

- Variations in solar radiation on Earth
- Physical properties of the atmosphere
- Coriolis effect impact on moving objects
- Global atmospheric circulation patterns
- Weather and climate patterns in the ocean
- Sea ice and icebergs
- Energy from wind over the oceans

10.1 Earth's seasons

- The Earth orbits around the Sun once a year
- The Earth's rotation axis is tilted at $23.5°$ with respect to the ecliptic

10.2 Uneven solar heating on Earth

- Solar energy is spread over a larger area
- More solar energy is reflected back into space because of the low angle of the sunlight
- Solar energy passes through more atmosphere which absorbs, scatters and reflects sunlight

10.3 Earth's seasons

- NH and SH are alternately tilted toward and away from the Sun each year
- In the summer hemisphere:
  - the days are longer
  - the Sun hits the Earth at a higher angle so radiation is concentrated over a smaller area
  - the higher angle also means more energy is absorbed and less reflected

10.4 Heat transport

- A net heat gain is experienced in low latitudes
- A net heat loss is experienced in high latitudes
- The equator does not get continuously hotter and the poles continuously cooler! Why? Heat gain and loss are balanced by oceanic and atmospheric circulation.

10.5 Physical properties of the atmosphere: Composition of dry air

Nitrogen and oxygen gas comprise 99% of the total, with several trace gases making up the rest; the most significant trace gas is carbon dioxide, an important greenhouse gas.

10.6 Physical properties of the atmopshere: Temperature

- The troposphere is lowermost 12 km of the atmosphere where most weather occurs
- Temperature in the troposphere decreases with increasing height.
- Outgoing long wavelength radiation from the Earth's surface is absorbed by GHG in the troposphere.
- The troposphere is primarily heated from the Earth's surface, not from incoming sunlight.

10.7 Physical properties of the atmopshere: Water vapour

- Air in the troposphere contains varying amounts of water. In gas form, water is called water vapour.
- The amount of water vapour in the atmosphere depends on air temperature.
- Cool air cannot hold so much water vapor, so is typically dry.
- Warm air can hold more water vapor, so is typically moist.

10.8 Physical properties of the atmopshere: Pressure

- A column of cool, dense air in the troposphere causes high pressure at the surface, which will lead to air diverging (moving away) at the surface.

10.9 Physical properties of the atmopshere: Movement

- Air is forced from high- to low-pressure regions
- Moving air is called wind

10.10 Vertical cells in the atmosphere

- The 3 vertical circulation cells:
  - Hadley 0 ° – 30 °
  - Ferrell 30 ° – 60 °
  - Polar 60 ° – 90 °
- Low pressure at 0 and 60 called the equatorial low and the subpolar low (rising air, rain)

10.11 Wind belts of the world

- The 3 wind belts
  - Easterly trade winds
  - Prevailing westerlies
  - Polar easterlies

10.12 Weather and climate patterns: Sea and land breeze

- Rocks heat up and cool down more quickly than water
- The air above warm rock will be warm, leading to low air pressure
- The air above cool water will be cool, leading to higher air pressure
- Air will flow at the surface from high to low pressure
- The situation will reverse at night because rock cools down more quickly

11 Lecture 5.1: Ocean currents

- Surface currents
  - Affect upper 1000 m in the ocean
  - Driven by major wind belts of the world
- Deep currents
  - Affect deep water below 1000 m depth
  - Driven by sea water density differences
  - Larger and slower than surface currents

11.1 Surface currents closely follow global wind belt pattern

- Trade winds at 0°-30° latitude blow surface ocean water to the west.
- Prevailing westerlies at 30°-60° latitude blow surface ocean water from west to east

11.2 Upwelling and downwelling

- Vertical surface layer movement (some 100s m depth)
  - Upwelling = movement of underlying water to the surface
    - Lifts cold, nutrient-rich water to surface
    - Produces high primary productivities and abundant marine life

12 Lecture 6: Water and seawater

Water has unusual chemical properties:

- Melting point
- Boiling point

Atomic structure:

- Nucleus contains:
  - Neutrons (no charge)
  - Protons (+ charge)
- Shells contain: electrons

Every chemical element (*grundämne*) is defined by the number of protons (and an equal number of electrons)

12.1 Different bonds

12.1.1 Covalent bond

intramolecular bond – atoms share electrons to form molecules

12.1.2 Ionic bond

intramorecular bond

12.1.3 Hydrogen bond

12.2 The water (H_2O) molecule has covalent bonds between H and O atoms

- Water is composed of 1 oxygen atom and 2 hydrogen atoms.
- Contains covalent bonds between oxygen and hydrogen atoms.
- Covalent bonds are when atoms share electrons.

12.3 Hydrogen bonds between water molecules

- Polarity causes water molecules to form weak (hydrogen) bonds between water molecules since the + and - sides are attracted to each other.

12.4 Water is a solvent

Sodium and chlorine form ionic bonds. The sodium atom gives an electron to the chlorine atom. It is a relatively weak bond.

12.5 Water exists in the 3 states of matter (solid, liquid and gas)

- Latent (hidden) heat = energy that is either absorbed or released from water as the water changes state.
- Heat is absorbed when chemical bonds break.
- Heat is released when bonds are created.

12.6 Hydrogen bonds in H_2O and the three states of matter

In the solid state there are hydrogen bonds between all water molecules.

In the liquid state there are some hydrogen bonds.

In the gas state, there are no hydrogen bonds, and the water molecules move rapidly and independently.

12.7 Snowflake geometry

Snowflake geometry is caused by the geometry of water crystalline structure.

12.8 Latent heats and changes of state of water

Latent heat of melting: 80cal/g

Latent heat of vaporization: 540cal/g

12.9 Comparison of melting and boiling points of water with similar chemical compounds

Water has much higher melting and boiling points thanks to having a 130° angle between hydrogen molecules (compared to a similar molecule if it had a 180° angle between molecules).

12.10 Heat capacity

- Heat capacity is the amount of energy required to raise the temperature of 1 gram of material 1C.
- Water has high heat capacity compared to other natural materials.

12.11 Ocean water stabilizes Earth's temperature change

- Water has high heat capacity, so it can absorb (or release) large quantities of energy with slow changes of temperature
- Ocean water moderates coastal temperatures

12.12 Surface tension

- Due to the polarity, water molecules want to cling to each other.
- At the surface, the outmost layer of molecules, has fewer molecules to cling to.
- Molecules compensate by establishing stronger bonds with its neighbours – this leads to the formation of the surface tension
- Other than mercury, water has the greatest surface tension of any liquid

12.13 Special properties of water due to polarity

- High surface tension
- Good solvent

- High heat capacity
- Latent heat of melting (80 cal)
- Latent heat of vaporization (540 cal)
- Density – water density increases with decreasing temperature BUT then decreases below 4° C
- Thermal expension – Contracts as it cools BUT expands below 4°
- Exists in 3 states on the surface of the earth: ice, liquid, gas

12.14 Sea water – composition of ocean salt

12.15 Salinity

- Salinity = total amount of solid material dissolved in water
- Can be determined by measuring water conductivity (how easy it is for electricity to flow)
- Typically expressed in parts per thousand

12.16 Surface salinity variation

- Pattern of surface salinity:
  - Lowest in high latitudes
  - Highest in the tropics
  - Decrease at the Equator
- Surface processes help explain pattern

12.17 Salinity variation with depth

- Measurements from different latitudes have different surface salinities
- Halocline = layer of rapidly changing salinity
- At depth, salinity is relatively uniform

12.18 Seawater density

- Factors affecting seawater density:
  - Temperature increases, density decreases
  - Salinity increases, density increases
  - Pressure increases, density increases
- Temperature has the greatest influence on surface seawater density

12.19 Temperature and density variations with depth

- **Pycnocline** = layer of strong changing density
- **Thermocline** = layer of strong changing temperature
- The pycnocline is a barrier to vertical mixing of water and migration of marine life.
- Isopycnal water columns allow water to vertically mix.

12.20 Ocean layering based on density

- Mixed surface layer (surface to 300 meters): low density; well mixed by waves, currents, tides
- Upper water (300 to 1000m): intermediate density water containing thermocline, pycnocline, and halocline
- Deep water (below 1000m): cold, high density water involved in deep current movement

12.21 Distillation

13 Lecture 7: Waves, water dynamics and tides

13.1 How are waves formed?

- Waves are created by energy release including:
  - Wind
  - Movement of media (air or fluids) of different densities:
    - Air-water = ocean waves
    - Air-air = atmospheric waves
    - Water-water = internal waves
  - Mass movement into the ocean (splash waves, but also commonly grouped into the category of tsunamis)
  - Underwater seafloor movement (tsunami)
  - Pull of the Moon and Sun (tides)
  - Atmospheric pressure changes (seiches)
  - Human activities (explosions)
- Progressive waves move energy, not mass!

13.2 Internal waves

Pycnocline = a layer in a body of water where the density changes rapidly with depth, typically separating warmer, less dense surface water from colder, denser deep water.

13.3 Most ocean waves are wind-generated

13.4 Types of progressive waves

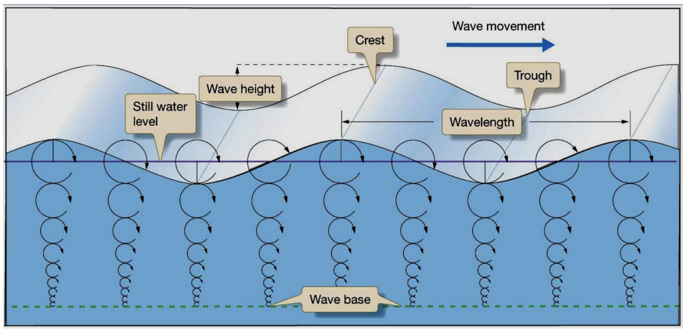
Progressive waves oscillate uniformly and travel without breaking.

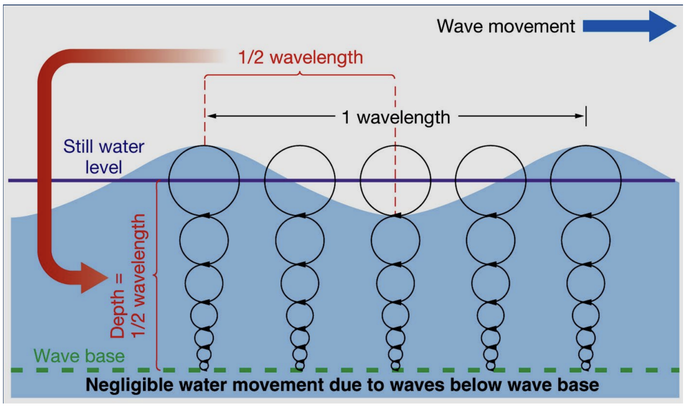
1. Longitudinal (compressional): back-and-forth particle motion in solid, liquid and gas
2. Transverse (shear): side-to-side particle motion in solids only (not in ocean)
3. Orbital (e.g. typical wind waves): combination of longitudinal and transverse in liquids and/or gas

13.5 Wave characteristics and terminology

- Crest
- Trough

- Wave height (H)
- Wavelength (L)
- Still water level
- Orbital motion
- Wave base





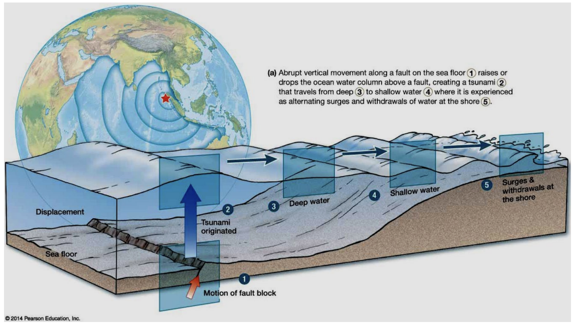
- Orbital size decreases with depth to zero at the wave base
- Depth of wave base = one half wavelength (L/2), measured from still water level

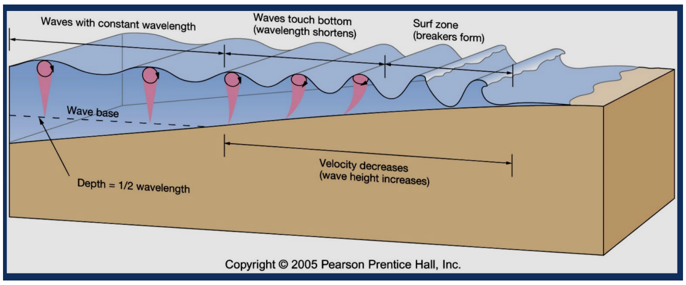
13.6 Wind waves and how they break when reaching the coasts

13.7 Wind driven wave

13.8 Waves undergo physical changes in the surf zone

- As swell moves towards the coast, the water depth decreases, and at water depth of half the wavelength, the wave energy touches the seafloor, and energy will eventually be released by breaking waves.
- As the base of the wave touches the seafloor, the wave speed decreases.
- The wave behind is still traveling at the same speed as before, so the wavelength decreases.
- Some energy is lost to friction, but the remaining energy must go somewhere, so the wave height increases.
- When the wave steepness (H/L) ¿ 1/7, breakers form and energy is released in the surf zone.





13.9 Wave interference patterns

- Constructive interference: troughs and crests aligned between two waves; increases wave height.
- Destructive interference: troughs of one wave lined up with crests of another wave; decreases wave height.
- Mixed: variable pattern.

13.10 Tsunamis

- Tsunami terminology:
  - Often called "tidal waves" but have nothing to do with the tides
  - Japanese term meaning "harbor wave"
  - Also called "seismic sea waves"
- Created by movement of the ocean floor by:
  - Underwater fault movement
  - Underwater slides
  - Underwater volcanic eruptions

Most tsunami originate from underwater fault movement.

13.11 Costal effects of tsunami

- If a trough arrives first, it appears as a strong withdrawal of water (similar to an extreme and suddenly-occurring low tide)
- If a crest arrives first, it appears as a strong surge of water that can raise sea level many meters and flood inland areas
- Tsunami often occur as a series of surges and withdrawals over hours

13.12 What are tides?

- Tides are the daily periodic raising and lowering of sea level.
- Tides are very long and regular shallow water waves.

13.13 What causes tides?

- Gravity
  1. Gravitational force of the Moon and Sun on Earth
     - If mass increases, then gravitational force increases
     - If distance increases, then gravitational force greatly decreases
  2. Centripetal (center-seeking) gravity force required to keep planets/moon/sun in nearly circular orbits around each other

14 Lecture 8: The coasts

14.1 Where is the coastline?

The location of the coastline depends on relative sea level and local slope. Relative sea level is the result of the competition between global sea level change and land uplift/subsidence (relative to the Earth's center).

Isostatic changes = changes in continent level

Eustatic changes = changes in sea level

14.2 Coastal waters – shelf areas

The width of the shelf varies a lot. The shelves generally wide in passive margins, and narrow near deep sea trenches (subduction zones).

14.3 Passive margins – coasts without a plate boundary

14.4 Passive margin (e.g. Atlantic coasts)

- Generally wide shelves where sediments accumulate
- Generally low relief (quite flat)

14.5 Active margin – subduction zone

- Generally narrow shelves
- Generally steep topography

14.6 Coastal landforms and terminology

- berm = standterass
- bar = (sand-)revel
- longshore = kustparallell
- notch = strandhak
- wave-cut cliff = klint
- trough = ränna/tråg
- wave-cut bench = strandflate

14.7 Sea floors are quite flat

14.8 Movement of sand in/out of the beach

Note that movement both in/out and along the beach occurs. Treating them separately makes it easier to understand.

Movement perpendicular to shorelines (in/out):

- caused by breaking waves
- weak wave activity moves sand up the beach face toward the berm
- strong wave activity moves sand out from the shore to the longshore bars

14.9 Movement of sand and water along the beach

14.10 Longshore current → longshore drift

Longshore current

- Zig-zag movement of water in the surf zone
- Speed increases with increasing beach slope, angle between beach and waves, wave height and wave frequency

14.11 Rip currents

- Narrow, fast, outward surface currents between breaking swells
- Note, Do NOT swim towards the beach. To escape a rip current, swim sideways along the beach until clear of the current.

14.12 Features of erosional shores – rising sea level

Deposition and erosion is common on all shorelines. But some shorelines are dominated by erosion or by deposition → indicates relative sea level.

- Erosional shores are typical of areas where tectonic uplift is much slower than sea level rise.

14.13 Delta

- Some rivers carry more sediment to the shoreline than can be carried away by longshore currents.
- When sediment deposition is larger than coastal erosion, a **bird-foot delta** is formed.
- When tides are the dominating process, the delta forms several funnel-shaped river mouths, because the rising and sinking sea level prevents a single channel to dominate.

14.14 Global sea level – eustasy

Rapid Eustatic changes are caused by variations in ocean water volume through ice sheets on the continents or thermal expansion (warm water is larger than cold water).

14.15 Evidence of emerging and submerging shorelines

Emergent (exposed) features: Marine terraces, raised beaches

Submergent (drowned) features: Drowned beaches, drowned river valleys

14.16 The formation of a wave cut platform/bench

14.17 Interfering with sand movement

Building hard structures on the beach into the sea changes the longshore current and longshore drift directions

Result: different distribution of sediment on the coastline

Sediments are deposited upstream of a groin and are eroded downstream of a groin.

14.18 Breakwaters – shelter for boats ...and sand

- Deposition in harbor and erosion downstream
- Sand must be dredged regularly

15 Lecture 8: Coastal waters

15.1 Salinity differences in the shallow coastal ocean

15.2 Temperature in the shallow coastal ocean

Strong thermoclines mainly in mid-latitudes, seasonal

15.3 Estuaries

- Partially enclosed coastal bodies of water where fresh runoff mixes with salty ocean water.
- Large variations in salinity and temperature.

15.4 Coastal wetlands

- Coastal wetlands = water saturated land areas that border coastal environments
- Periodically submerged by ocean water
- Oxygen poor sediment → slow/no degradation → accumulate organic-rich peat deposits
- Two most important types of coastal wetlands:
  - Salt marshes (mid-latitudes)
  - Mangrove swamps (low-latitudes)

16 Chapter 8: Waves and water dynamics

16.1 Glossary of terms

- **disturbing force** –
- **ocean waves** –
- **atmospheric waves** –
- **internal waves** –
- **longitudinal waves** –
- **transverse waves** –
- **orbital waves** –
- **crests** –
- **troughs** –
- **still water level** –
- **wave height** –
- **wavelength** –
- **wave steepness** –
- **wave period** –
- **frequency** –
- **circular orbital motion** –
- **wave base** –
- **deep-water waves** –
- **wave speed** –
- **shallow-water waves** –
- **transitional waves** –
- **capillary waves** –
- **gravity waves** –
- **sea area** –
- **Beaufort Wind Scale** –
- **fully developed sea** –
- **swell** –
- **wave train** –
- **wave dispersion** –
- **decay distance** –
- **interference pattern** –
- **constructive interference** –
- **destructive interference** –
- **mixed interference** –
- **surf beat** –
- **rogue waters** –
- **surf zone** –

- **shoaling** –
- **spilling breaker** –
- **plunging breaker** –
- **surging breaker** –
- **surfing** –
- **refraction** –
- **orthogonal lines** –
- **wave reflection** –
- **standing waves** –
- **tsunami** –
- **splash waves** –

17 Chapter 9: Tides

- **barycenter** –
- **gravitational force** –
- **Newton's law of universal gravitation** –
- **zenith** –
- **nadir** –
- **centripetal force** –
- **resultant forces** –
- **tide-generating forces** –
- **lunar bulges** –
- **tidal period** –
- **lunar day** –
- **solar day** –
- **solar bulges** –
- **flood tide** –
- **ebb tide** –
- **new moon** –
- **full moon** –
- **quarter moon** –
- **tidal range** –
- **spring tide** –
- **syzygy** –
- **neap tide** –
- **quadrature** –
- **waxing crescent** –
- **waxing gibbous** –
- **waning gibbous** –
- **waning crescent** –
- **declination** –
- **ecliptic** –
- **perihelion** –
- **aphelion** –
- **perigee** –
- **apogee** –
- **proxigean** –
- **amphidromic point** –
- **cotidal lines** –
- **diurnal tidal pattern** –
- **semidiurnal tidal pattern** –
- **mixed tidal pattern** –
- **rotary current** –
- **reversing current** –
- **flood current** –
- **ebb current** –
- **high slack water** –
- **low slack water** –
- **whirlpool** –
- **grunion** –

18 Lecture 9: Waves

18.1 How are waves formed?

- Waves are created by energy release (disturbances) including:
  - Wind
  - Movement of media (air or fluids) of different densities
    - Air-water = ocean waves
    - Air-air = atmospheric waves
    - Water-water = internal waves
  - Mass movement into the ocean (splash waves, but also commonly grouped into the category of tsunamis)
  - Underwater seafloor movement (tsunami)
  - Pull of the Moon and Sun (tides)
  - Atmospheric pressure changes (seiches)
  - Human activities (explosions)
- All are examples of progressive waves, they move energy, not mass!

18.2 Waves

Generated by wind (air-water)

When and how they break depends on the depth and shape of the seafloor

18.3 Tsunami

Seafloor movement, underwater volcanism and slides.

18.4 Internal waves

An internal wave moving along the density interface (pycnocline) below where surface waves occur.

18.5 Most ocean waves are wind-generated

18.6 Types of progressive waves

(progressive waves oscillate uniformly and travel without breaking)

1. Longitudinal (compressional): back-and-forth particle motion in solid, liquid and gas
2. Transverse (shear): side-to-side particle motion in solids only (not in ocean)
3. Orbital (e.g. typical wind waves): combination of longitudinal and transverse in liquids and/or gas

18.7 Wave characteristics – orbital motion in waves

- Orbital size decreases with depth to zero at the wave base
- Depth of wave base = one half wavelength (L/2), measured from still water level

18.8 Wind waves and how they break when reaching the coasts

18.9 Waves undergo physical changes in the surf zone

18.10 Wave interference patterns

- Constructive interference: troughs and crests aligned between two waves; increases wave height
- Destructive interference: troughs of one wave lined up with crests of another wave; decreases wave height
- Mixed: variable pattern

18.11 Tsunami

- Tsunami terminology
  - Often called "tidal waves" but have nothing to do with the tides
  - Japanese term meaning "harbor waves"
  - Also called "seismic sea waves"
- Created by movement of the ocean floor by
  - Underwater fault movement
  - Underwater slides
  - Underwater volcanic eruptions

Tsunami waves have much much longer wavelength than wind waves, but much much lower amplitude.

18.12 Coastal effects of tsunami

- If a trough arrives first, it appears as a strong withdrawal of water (similar to an extreme and suddenly-occuring low tide)
- If a crest arrives first, it appears as a strong surge of water that can raise sea level many meters and flood inland areas
- Tsunami often occurs as a series of surges and withdrawals over hours

19 Lecture 9: Tides

What are tides?

- Tides are the daily periodic raising and lowering of sea level
- Tides are very long and regular shallow water waves

What causes tides?

- Gravity
  - Gravitational force of the Moon and Sun on Earth
    - If mass increases then gravitational force increases
    - If distance increases, then gravitational force greatly decreases
  - Centripetal (center-seeking) gravity force required to keep planets/moon/sun in nearly circular orbits

19.1 Effect of elliptical orbits of Sun and Moon

- Tidal ranges are greater when
  - The Moon is at perigee
  - The Earth is at perihelion

19.2 Tidal patterns

- Diurnal: one high and one low tide each (lunar) day
- Semidiurnal: two high and two low tides of about the same height daily
- Mixed: characteristics of both diurnal and semidiurnal with successive high and/or low tides having significantly different heights

19.3 Summary of tides on an idealized Earth

- All locations except the poles have two high tides and two low tides per lunar day

20 Chapter 12: Marine Life and the Marine Environment

20.1 Glossary of terms

- **bacteria** – one of three major domains of life. The domain includes unicellural, prokaryotic microorganisms that vary in terms of morpholofy, oxygen and nutritional requirements, and motility.
- **archaea** – one of three major domains of life. The domain consists of simple microscopic bacterialike creatures (including methane producers and sulfur oxidizers that inhabit deep-sea vents and seeps) and other microscopic life-forms that prefer environments of extreme conditions of temperature and/or pressure.
- **eukarya** – one of three major domains of life. The domain includes single-celled or multicellural organisms whose cells usually contain a distinct membrane-bound nucleus.
- **eubacteria** –
- **archaebacteria** –
- **plantae** –
- **animalia** –
- **fungi** –
- **protista** –
- **protozoa** –
- **species** –
- **plankton** –
- **plankter** –
- **biomass** –
- **autotrophic** – algae, plants, and bacteria that can synthesize organic compounds from inorganic nutrients
- **phytoplankton** –
- **heterotrophic** –
- **zooplankton** –
- **bacterioplankton** –
- **virioplankton** –
- **holoplankton** –
- **meroplankton** –
- **macroplankton** –
- **picoplankton** –
- **benthos** – the forms of marine life that live on the ocean bottom
- **epifauna** –
- **infauna** –
- **nektobenthos** –
- **pelagic sediment** – sediment composed primarily of fine lithogenous and biogenous particles that is deposited slowly on the deep ocean floor: also called pelagic deposits
- **pelagic environment** – the open-ocean environment which is divided into the neritic province (water depth 0 to 200 meters or 656 feet) and the oceanic province (water depth greater than 200 meters or 656 feet)
- **protoplasm** – the self-perpetuating living material making up all organisms, mostly consisting of the elements carbon, hydrogen, and oxygen combined into various chemical forms.
- **viscosity** – a property of a substance to offer resistance to flow caused by internal friction.
- **streamlining** – the shaping of an object so it produces the minimum of turbulence while moving through a fluid medium. The teardrop shape displays a high degree of streamlining.
- **broadcast spawning** –
- **stenothermal** – pertaining to organisms that can withstand only a small change of temperature change
- **eurythermal** –
- **euryhaline** –
- **stenohaline** – pertaining to organisms that can withstand only a small range of salinity change
- **osmosis** – the process by which water molecules move through a semipermeable membrane from higher water molecule concentration (lower concentration) to lower water molecule concentration (higher salinity).
- **osmotic pressure** – a measure of the tendency for osmosis to occur. It is the pressure that must be applied to the more concentrated solution to prevent the passage of water molecules into it from the less concentrated solution.
- **hypotonic** – pertaining to the property of an aqueous solution having a lower osmotic pressure (salinity) than another aqueous solution, from which it is separated by a semipermeable membrane that will allow osmosis to occur. The hypotonic fluid will lose water molecules through the membrane to the other fluid.
- **gills** –
- **countershading** –
- **deep scattering layer (DSL)** – a layer of marine organisms in the open ocean that scatter signals from an echo sounder. It migrates daily from depths of slightly over 100 meters (330 feet) at night to more than 800 meters (2600 feet) during the day.
- **erepuscular** –
- **disruptive coloration** –
- **swim bladder** –
- **biozone** –
- **neritic provinence** –

- **oceanic provinence** –
- **epipelagic zone** –
- **mesopelagic zone** –
- **bathypelagic zone** –
- **abyssopelagic zone** –
- **euphotic zone** –
- **disphotic zone** –
- **aphotic zone** –
- **oxygen minimum layer (OML)** – a zone of low dissolved oxygen concentration that occurs at a depth of about 700 to 1000 meters (2300 to 3280 feet)
- **bioluminescence** –
- **detritus** –
- **supralittoral zone** –
- **subneritic provinence** –
- **suboceanic provinence** –
- **littoral zone** – the benthic zone between the highest and lowest spring tide shorelines, also known as the intertidal zone
- **sublittoral zone** –
- **bathyal zone** –
- **abyssal zone** –
- **hadal zone** –

21 Lecture 10: Marine life

21.1 Marine environments

Neritic zone: shallow shelf zone, where light reaches to seafloor, abdundant food, abundant life

Benthic zone: seafloor

- epipelagic zone: 0-100m (continental shelf)
- mesopelagic zone: 100-1000m
- bathypelagic zone: 1000m-4000m
- abyssal zone: 4000-6000m
- deep-sea trenches and hadal zone

21.2 Classification of marine life

protozoa = unicellural organisms

prokaryota (bacteria and archaea) = unicellural organisms, without a membrane bound nucleus

eukaryota = unicellural and multicellural organisms with a membrane-bound nucleus: plantae, chromista, protista, fungi, animalia

21.3 Classification of marine life: 3 categories

- plankton: unable to swim: float
- nekton: active swimmers
- benthos: bottom living

21.4 Marine ecosystems = aquatic ecosystems that have high salt content

Nearshore (neritic) ecosystems:

- saltmarshes
- mudflats
- sea-grass meadows
- mangroves
- rocky intertidal systems/kelp forests
- coral reefs

Offshore ecosystems:

- surface ocean: pelagic ocean waters
- ocean floor:
  - deep benthic habitats, typical seafloor
  - oceanic hydrothermal vents and cold seeps

Ca. 60% of the Earth's surface is in the pelagic zone: therefore, phytoplankton primary production is very important to global primary production and carbon cycling

21.5 Nekton (swimmers)

- Animals that move independently
- Adult fish, marine mammals, marine reptiles, some marine invertebrates (squid)
- Temperature, salinity, viscosity, pressure, nutrients influence where the nekton can live
- Fish are most common near continents, islands and in cold water.
- Some fish leave the ocean to spawn in fresh water (salmon). Some eels move from fresh water to the ocean to spawn.
- Jellyfish and other species are considered plankton when they are small/juvenile and nekton when they are larger

21.6 Benthos (bottom dwellers)

- Organisms that live on or in the ocean bottom.
- Epifauna: organisms live on the surface, either attached or moving on the bottom.
- Infauna: organisms live within sand or mud of the sea bottom.
- Nektobenthos: some animals can swim or crawl on the bottom.

- Shallow benthos survive on photosynthetic biomass growing on the bottom substrate. Therefore, benthic biomass decreases with increasing depth due to decreasing sunlight and therefore decreasing vegetable food.
- In deeper water offshore, benthic animals eat detritus falling from the surface ocean or continent, or each other (carnivorous).
- In the deep ocean (¿2000m) where no light penetrates, most organisms are dependent on detritus food sources raining down from the surface (¡0.1% of total primary production reaches the seafloor). Food is scarce, therefore deep benthic biomass is very low biomass.

21.7 Marine biodiversity: oceans vs land

- Fewer species are found in the oceans compared to land (lower diversity in the oceans).
- This is because the oceans are more homogenous environments, they are well connected by ocean currents, and well "mixed" by wind, waves and currents, meaning there are fewer places or habitats for organisms to isolate and speciate.
- In contrast, on land there is much greater variety in the types of environments providing much more ecospace and different habitats for organisms to evolve and adapt into.
- Marine species make only 14% of the 1800000 world species.

21.8 Benthic species are far more diverse than pelagic species

This is because the pelagic ocean beneath the penetration of sunlight is most homogenous, well mixed, therefore limited ecological niches.

In contrast, the ocean floor (benthic environment) is more diverse, especially closer to land, e.g. rocky, sandy, muddy, slopes, etc., which requires adaptations to live and creates diverse ecospace.

On the other hand, pelagic species (making up only 2% of 250000 marine species 98% of benthic), have a much bigger total biomass.

21.9 Adaptations to life in salty water: a dense fluid

- Sea water is 827x more dense than air.
- This combined with other physical, chemical and biological factors, presents challenges, and opportunities to life in the seas.
- Some of the physical conditions and challenges of living in the marine realm are:
  - Viscous fluid
  - Salt (chemistry challenges)
  - Drinking (not drinking too much salt)
  - Stay in the photic zone (where food is) and not sink
  - Breathing in and out
  - Dealing with high pressure
  - Fighting against the winds, tides and currents to stay where you want to be
  - Reproduction
  - Communicating
  - Seeing
  - Hearing
  - Staying warm or cool

21.10 Life in a viscious fluid

Body support: sea water provides buoyance, therefore bodies are better supported in water. This allows ocean organisms to be huge, like the blue whale.

Size also matters for small organisms:

- Plankton are usually small, small enough that internal viscosity, friction forces of water dominate the behaviour of the water acting on them. Therefore they can stay in the photic zone without doing much: rely on friction and natural buoyance to stay where they need to be.
- Nekton are larger and interact with their environment at high Reynolds numbers where turbulent flow and inertial forces dominate. They must actively swim to do what they need to do.

21.11 Life in a viscous fluid: low Reynold Numbers

Low Reynolds Number means that mostly internal forces dominate and organisms can stay in place by affecting how the water flows around them.

21.12 Life in a viscous fluid: high Reynold Numbers

Larger organisms have high Reynolds numbers, therefore optimize their swimming speed by having a specially modified body shape that helps displace water ahead and move it behind itself.

Streamlining = the animals evolve a fish shape with a flattened body, small cross section at the front, and tapered tail. Fish shaped body!

21.13 Surviving in salt water

Adaptation to salinity: saltwater fish

- Saltwater fish adapt by constantly drinking water and expelling salt using chloride-releasing cells in the gills.
- The saltwater fish also discharge very small amounts of concentrated urine.
- It would be very damaging for a salt water fish to go into freshwater: it would drink too much fresh water and risk rupturing its cells.
- Whales, dolphins and other sea-dwelling mammals: do not drink seawater. They obtain water from their food and by producing it internally from the metabolic breakdown of food.

21.14 Oxygen intake and breathing in the marine environment

- Single-celled organisms and jellyfish absorb O_2 and exchange CO_2 across their cell membranes
- Marine mammals and bird and some air-breathing fish, hold their breath then periodically come up for air.
- Most fish and invertebrates get their oxygen in dissolved form from water.

21.15 Ocean biological productivity, food chains and energy transfer

- The oceans are responsible for over 40% of global primary production.
- Therefore, they play a major role in the global carbon cycle by consuming CO_2 from the atmosphere and positively influencing climate change (CO_2 sink).
- Microalgaea are responsible for over 50% of this production, with macroalae (kelp forests) contributing the rest.
- The oceans are a major source of food.

21.16 Biological productivity and energy transfer

- Primary production is not equally spread out. There are ocean deserts and hotspots.
- In the open ocean, the highest zones of biological production coincide with regions oceanic upwelling, where nutrients are brought to the surface.

21.17 Ocean biological productivity: geography and oceanography

- The low latitudes have a permanent thermocline that prevents upwelling, therefore nutrients are scarce in the surface ocean = low surface production.
- Equatorial upwelling, Southern Ocean, North Pacific, coastal and other upwelling regions, are exceptions = strong primary production.
- Shallow, tropical environments: coral reefs have low nutrients. Rely on symbiotic algae living with the coral to produce biomass and build strong ecosystems = strong primary production.
- Climatic warming causes stronger stratification, reduces mixing and results in lower ocean O_2 content which is damaging to marine ecosystems: O_2 has dropped by 2% in the last 50 years.

21.18 The future looks good for jelly fish

- Very long geological history: 600 million years = resilient
- Their increasing abundance has sparked increasing research
- Key question: what other animals eat jellyfish considering they are 95% water?
- Answer: jellyfish are regular food: low calorie, but abundant and easy to digest.
- Jelly fish are environmentally tolerant, also overfishing has led to decreasing populations of jellyfish predators and competitors for food, thus helping populations rise.
- And there could be a pay off: although mostly water, jellyfish accumulate carbon: large populations, large carbon sink to help sequester carbon in the deep sea (and diminish CO_2 increase)

Meanwhile:

- Increased jellyfish abundance close to shore, is pest: painful strings to swimmers.
- Problems for industry: can stop nuclear power plants from functioning because jellies clog cooling filters, which can require plants to shut down.
- This has happened all over the world, including Scotland's Torness power plant, Oskarshamn power plant in Sweden, Japan, Israel.

21.19 Summary and closing remarks

- Marine organisms are diverse occupying planktonic and benthic habitats.
- Salt water presents many challenges to life in the oceans, requiring many adaptations.
- Ocean food chains start with microscopic algae and are responsible for 40% global primary production: important for global carbon cycling.
- Plankton and other marine organisms are suffering due to climate change.
- Warming oceans are causing increased stratification with less mixing meaning that oxygen becomes depleted, suffocating plankton and other organisms.
- This is concerning because plankton are at the base of food webs, supporting fisheries and all the other diverse organisms.