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

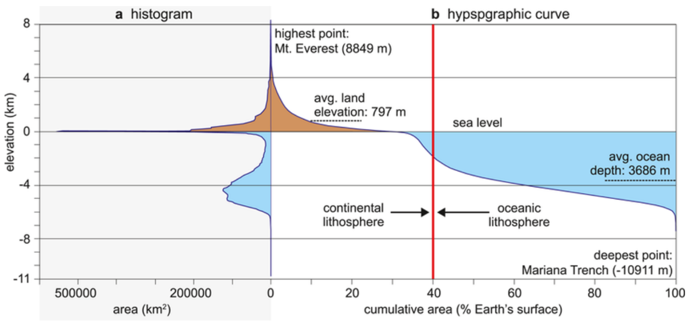
- **oceans** – the entire body of saltwater that covers 70% of Earth's surface
- **nebula** – a huge cloud of gas and space dust
- **nebular hypothesis** – all bodies in the solar system formed from an enormous cloud composed mostly of hydrogen and helium with only a small percentage of heavy elements
- **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.



- 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.

2.1 How do we know the Earth's interior?

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

2.1.1 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).

2.1.2 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.

2.1.3 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.

2.1.4 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.

2.2 Composition of the Earth

2.2.1 Crust

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

2.2.2 Mantle

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

2.2.3 Outer core

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

2.2.4 Inner core

- Iron: 94%
- Nickel: 5%

2.3 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.

2.4 Different plate margins, different results

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

2.5 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.

2.6 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

2.7 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

2.8 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.

2.9 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!

2.10 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 → sloping sea surface → 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** –

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.

8 Chapter 6: Air-Sea Interaction

8.1 Glossary of terms

- **plane of the ecliptic** –
- **vernal equinox** –
- **summer solstice** –
- **Tropic of Cancer** –
- **autumnal equinox** –
- **winter solstice** –
- **Tropic of Capricorn** –
- **declination** –
- **tropics** –
- **Arctic Circle** –
- **Antarctic Circle** –
- **solar footprint** –
- **atmospheric absorbtion** –
- **albedo** –
- **reflection of incoming sunlight** –
- **troposphere** –
- **convection cell** –
- **wind** –
- **Coriolis effect** –
- **Hadley cells** –
- **Ferrel cell** –
- **polar cell** –
- **subtropical highs** –
- **polar highs** –
- **equatorial flow** –
- **subpolar flow** –
- **trade winds** –
- **northeast trade winds** –
- **southeast trade winds** –
- **prevailing westerly wind belts** –
- **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