# 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

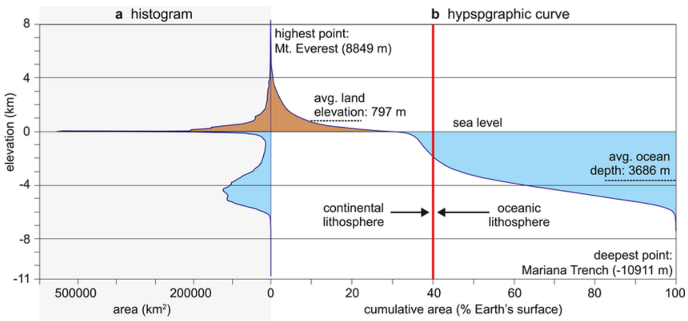
- **oceans** – the entire body of saltwater that covers 70% of Earth's surface
- **nebula** – a huge cloud of gas and space dust
- **nebular hypothesis** – all bodies in the solar system formed from an enormous cloud composed mostly of hydrogen and helium with only a small percentage of heavy elements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