

Ocean 201 week 2 Lecture 2: Earth Structure (M.J. Mottl)

Text from slides

Early History of the Earth

- Rapid accretion of Earth and attendant dissipation of kinetic energy caused tremendous heating. Earth possibly melted completely.
- In molten state, *differentiation* would occur: heavy elements would sink and lighter elements would move outward.

Origin of Oceans/Atmosphere: I

- Core formation was largely complete by 4.4 Ga.
- Accretion and differentiation of Earth would have created the first atmosphere by *outgassing*.
- Atmosphere is thus of *secondary* origin:
derived by outgassing of interior
rather than directly from solar nebula.
- Evidence: Earth is depleted in noble gases (He, Ar, Ne, etc.).
- Alternative hypotheses: heterogeneous accretion of *late veneer*, possibly from comets.

Origin of Oceans/Atmosphere: II

- Water as a *volatile* compound would have been outgassed from early Earth BUT Earth's surface was too hot for a liquid ocean.
- Is Earth fully outgassed today? Estimates range from 20% to nearly complete. (Some even think Earth is ingassing!)
- Outgassing was likely faster from early Earth:
heat production by radioactive decay was 4-5 times greater than today;
outgassing would have been correspondingly faster.

Origin of Oceans/Atmosphere: III

- Outgassing of Earth continues today. Evidence: ^3He detected in ocean, released from interior of Earth by volcanic processes

Composition of Volcanic Gases

- TODAY....
- 80% H₂O
 - 10% CO₂
 - 6% SO₂
 - 1% H₂
 - Trace of N₂, HCl
 - Major gases are in oxidized form now.
 - Early volcanic gases were likely in more reduced form:
H₂, CH₄, H₂S, NH₃.

Early atmosphere: Free O₂ would have been absent.
CO₂ and CH₄ were probably abundant.

The CO₂ would have eventually reacted with rocks (in water):



Solar Luminosity

- Luminosity of Sun has increased by 30% over 4.5 Ga.
- Change in luminosity has altered Earth temp.
- Early Earth T = 248K (-130F, -250C)
- Current T = 288K (590F, 150C)
- “Faint early sun paradox”: why did Earth’s early oceans not freeze over?
- ***CO₂ and/or CH₄ methane in the early atmosphere may be the answer.***

Structure of the Earth:

Inner core: solid Fe-Ni

Outer core: liquid Fe-Ni

Mantle: rocky: Mg-Fe silicate

Crust: rocky: Mg-Fe-Al-Ca silicate

Oceans: H₂O with dissolved salts

Atmosphere: N₂, O₂, Ar

How do we know?

Seismic Waves: I

- Generated by earthquakes (or explosions)
- Two types: P and S waves

Waves ***radiate*** from source in all directions.

Seismic Waves: II

P-waves:

- ***Primary*** waves
- Faster than S waves
- Compressional
- Travel through solid, liquid, or gas.
- Like a spring compressing and dilating

Seismic Waves: III

S-waves:

- ***Secondary*** waves
- Slower than P waves
- Shear waves
- Like undulation of string
- Do not propagate through a liquid or gas:
no restoring force in liquid.

Seismic Waves: IV

Seismic Waves: V

Waves bend in response to changes in properties of material.
 S-wave shadow zone
 P-wave shadow zones

Internal Structure of the Earth: I

(based on chemical and physical properties)

- **Inner Core:** 5100-6370 km, **solid** Fe + 6% Ni (16 g/cm³)
- **Outer Core:** 2900-5100 km, **liquid** Fe-Ni (12 g/cm³)
- Core is 32% of Earth mass, 16% of its volume
- **Mantle:** ~10-2900 km, solid Mg-Fe-silicates (4.5 g/cm³), 68% of Earth mass, 83% of its volume
- **Crust:** the “skin” of Earth:
0.4% of Earth mass and <1% of its volume.

Internal Structure of the Earth: II

(based on physical properties)

Use viscosity and strength to describe outer layers:

- **Lithosphere:** 0-100 km
= mantle + crust
- **Asthenosphere:** 100-700 km
= mantle
- **Mesosphere:** 700-2900 km
= mantle

BULK COMPOSITION OF THE EARTH

	<u>wt.%</u>	
Fe	36.0	85 ± 4 % of Fe is in the core (metallic).
O	28.7	
Mg	14.8	(Upper) Mantle: rocky: mainly Mg-silicates.
Si	<u>13.6</u>	
Subtotal:	93.1%	
Ni	2.0	
Ca	1.7	
S	1.7	
Al	1.3	
TOTAL:	98-99%	

Why does Earth have oceans?

- Lots of liquid water available... but why?
 - 1) rapid accretion of cold, icy, water rich planetesimals
(allowed retention of “volatile” H₂O after ice melted)
 - 2) outgassing of interior of Earth brought H₂O to surface
 - 3) moderate distance from Sun → moderate temperature
→ allowed H₂O to be present in liquid form
- Do other bodies in the Solar System have oceans? YES!
- **Mars** probably had oceans in the distant past.

- **Europa**, a moon of Jupiter, may have oceans under thick ice.
- **Titan**, a moon of Saturn, may have liquid hydrocarbon oceans, with continents of rock, H₂O ice, and CO₂ ice.

Earth and its nearest neighbors

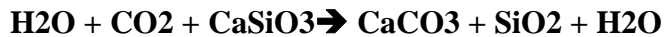
All 3 planets (Venus, Earth, Mars) have similar noble gas abundance ratios, implying grossly similar composition and outgassing history.

COMPARATIVE PLANETOLOGY

	Mass	Radius	Density	Distance from Sun	Surf. Temp.	Surface Press.	ATMOSPHERE:			
	10 ²⁶ g	km	g/cm ³	10 ⁶ km		atmos.	H ₂ O %	CO ₂ %	N ₂ %	O ₂ %
Venus	49	6050	5.3	108	750°K	100	0	96.5	3.5	0
Earth	60	6370	5.5	150	288°K	1	<1	0.03	78	21
Mars	6.4	3390	3.9	228	210°K	0.006	0.1	96	2.5	0.25

Inventory of CO₂, in units of 10²⁰ moles:

Earth , in crust, atmosphere, and oceans:	75
in mantle:	150
Venus , in atmosphere:	120



Venus has outgassed a similar amount of CO₂ as Earth, but it stayed in the atmosphere, causing a “*runaway greenhouse*”.

On Earth this CO₂ is locked up in rocks!

High temperatures caused Venus to lose all of its H₂O (260 atm-worth!) by *photodissociation* followed by loss of H₂ to space.

Venus would lose an Earth’s oceans worth of H₂O in 30 to 300 million years.

Comparison of Atmospheres: Venus vs. Earth

- N₂ has remained in atmosphere on Venus just like it has on Earth...
- Low relative concentration on Venus results from dilution by the highly abundant CO₂ in the Venusian atmosphere.

Comparison of Atmospheres: Mars vs. Earth

Mars’ atmosphere is 1/150 that of Earth’s. Mars is small and cold!

N₂ was lost to space: ~1 atm in 4.5 billion years.

H₂O and CO₂ are frozen in the polar caps and regolith (soil).

SUMMARY:

Fate of Planetary Gases (volatile compounds)

	<u>Earth</u>	<u>Venus</u>	<u>Mars</u>
H₂O	oceans	H—space O—rocks (1 ocean in 30-300 million years)	ice
CO₂	rocks	atmosphere	ice
N₂	atmosphere	atmosphere	space (1 atm in 4.5 billion years)
O₂	atmosphere	none	none

EVOLUTION OF THE OCEAN-ATMOSPHERE SYSTEM:

THE RISE OF FREE OXYGEN (O₂)

- Earth is chemically *reducing* (lots of metallic Fe).
- Must separate reduced from oxidized: e.g., core formation.
- O₂ must be produced:
 - 2 H₂O = 2 H₂ + O₂ **Photodissociation**
 - followed by loss of hydrogen to space.
 - CO₂ + H₂O = CH₂O + O₂ **Photosynthesis**
 - (Respiration and Decay)
 - followed by burial of organic carbon.
- Free oxygen probably arose about 2.4 Ga,
and reached near-present levels about 0.8 Ga.
- This allowed development of multicellular organisms
and their migration onto land.