But first...

- PDFs for Lectures 7, 8, and 11 are posted
- Paper 3 is due at beginning of class Thursday
- Paper 4 is now posted online
- Paper 4 is due at beginning of class on Mar. 13
  - No extensions over Spring Break!
- Lectures 9 and 10 will be posted online soon

Earth as a Planet

- Overview of Earth's basic properties
- Earth's Surface and Interior
  - Surface Geologic Processes
  - Composition and Structure
  - Evolution of the Surface
- Earth's Atmosphere and Climate
  - Earth's atmosphere
  - Weather and climate
  - The greenhouse effect
  - Cosmic influences on the biosphere
Basic Properties of the Earth

Average Distance from Sun: 150 million km = 1 A.U.
Period of Rotation around Sun: 365.25 days = 1 year
Period of Spin: 23 hours, 56 minutes, 4 sec = 1 day
Mass = $5.98 \times 10^{24}$ kg = 1 $M_E$
Radius = 6378 km = 1 $R_E$
Density = 5.5 g/cm³
Escape Velocity = 11.2 km/sec (~25,000 mph) = $v_E$
Atmospheric Pressure = $10^5$ N/m² = 1 bar = $P_E$
Most of surface covered by liquid water
Atmosphere mostly N₂, but with abundant free O
Surface geologically active and young!

Other Properties

- Earth has one large Moon
- Earth has a strong Magnetic Field

Earth's Surface Topography

Earth's topography is "bimodal"
- Deepest: -11 km
- Highest: +8.8 km
- 71% under water

Composition of the Earth’s Crust

- Earth's crust is only ~ 0.4% of Earth's mass
- But it is what we directly sample!
- Earth's crust consists of three rock types:
  - **Igneous**: Rocks melted then cooled
  - **Metamorphic**: Rocks changed by heat+pressure
  - **Sedimentary**: Fragments created by erosion

<table>
<thead>
<tr>
<th>Element</th>
<th>Approximate Percentage by Weight</th>
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<tbody>
<tr>
<td>Oxygen (O)</td>
<td>46.6</td>
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<tr>
<td>Silicon (Si)</td>
<td>27.7</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>8.1</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>5.9</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>3.6</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>2.8</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>2.6</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>2.1</td>
</tr>
<tr>
<td>All others</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Sedimentary Rock

- Layers, beds, dunes, etc.
- Formed by wind, water, ice

Metamorphic Rock

- High pressure
- High temperature
- Compression and folding of previous igneous or sedimentary rocks

Igneous Rock

- Example: volcanic rock from Hawaii
- Dozens of active volcanoes on Earth today!
- Not all igneous rock is erupted onto the surface
The Plates Move!
Lots of Action at Plate Boundaries...

Volcanoes of the World (USGS)

Earth's Surface is Divided into Plates!

The fact that the plates move was highly controversial when first proposed (Wegener, 1915)

"Anecdotal" evidence:
S. America & Africa fit like a jigsaw puzzle

Better evidence:
Magnetic "stripes" on the seafloor

Other evidence:
- Similar fossils across continents
- Similar rocks across continents
- Earthquakes at plate boundaries
- Very young age of seafloor
Abundant geologic evidence of tectonic forces at work on our home world

And these forces have been acting for long periods of time!

Have there been asteroid impacts on the Earth?

- Several hundred impact craters identified on Earth
- Most highly degraded by wind, water, ice, tectonics
- Geologically "rare"

Yes!

Earth: What's Inside?

- ρ implies rock+metal
- "Onion Skin" layering
  - From differentiation
- Crust, Mantle, Core
  - Crust is thin (5-10 km) under oceans
  - Crust is thick (20-70 km) under continents
  - Mantle is hot but solid --> convection
  - Core is liquid (outer) or metallic (inner)
How do we know what's inside?

We can directly measure the behavior of seismic waves that travel through the Earth's interior.

Earth's Atmosphere

### Composition of the Earth's Atmosphere

<table>
<thead>
<tr>
<th>Gas Symbol</th>
<th>Symbol</th>
<th>Percent</th>
<th>PPM</th>
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<tbody>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>78.08</td>
<td>2088</td>
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<tr>
<td>Oxygen</td>
<td>O</td>
<td>20.95</td>
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<tr>
<td>Argon</td>
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<td>3</td>
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<tr>
<td>Helium</td>
<td>He</td>
<td>0.0005</td>
<td>0.5</td>
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<tr>
<td>Hydrogen</td>
<td>H</td>
<td>0.00006</td>
<td>0.6</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>0.00008</td>
<td>0.95</td>
</tr>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Vap</td>
<td>H2O</td>
<td>0 to 4</td>
<td>364</td>
</tr>
<tr>
<td>Carbon Mon</td>
<td>CO2</td>
<td>.0364</td>
<td>364</td>
</tr>
<tr>
<td>Methane</td>
<td>CH4</td>
<td>.00018</td>
<td>1.8</td>
</tr>
<tr>
<td>Nitric Ox</td>
<td>NO</td>
<td>.00031</td>
<td>3.1</td>
</tr>
<tr>
<td>Dioxide (Troposphere)</td>
<td>O2</td>
<td>.00004</td>
<td>0.4</td>
</tr>
<tr>
<td>Dioxide (Stratosphere)</td>
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<td>.00012</td>
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<tr>
<td>Particulates</td>
<td></td>
<td>.00001</td>
<td>1</td>
</tr>
<tr>
<td>Chlorofluorocarbons</td>
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<td>0.00001</td>
<td>0.01</td>
</tr>
</tbody>
</table>

- Highly oxidizing atmosphere ("Non-Equilibrium")
- Surface pressure: 1 bar (~ 1 kg/cm²)
- 1 bar = 10 m of water
- Oceans equivalent to 300 bars!

Origin of the Atmosphere

- Three main possibilities:
  - (1) Primordial: Formed along with the rest of the Earth ~4.6 billion years ago
  - (2) Internal: Gases released by volcanism over the history of the Earth
  - (3) Extraterrestrial: Volatiles delivered from impacts of icy comets and asteroids

**Volatiles**: materials that evaporate at relatively low temperatures

Atmospheric Gains

Atmospheric Losses
"Weather" vs. "Climate"

- Day-to-day, quasi-random fluctuations in atmospheric circulation and precipitation are called weather.
- Patterns of weather observed over decades to centuries are the climate.
- Weather changes quickly; climate slowly.
- Climate changes have occurred throughout Earth's history (how do we know this?)

Evidence for Past Climate Change

- Geologic evidence for massive glaciations: glacially-carved landforms, transported boulders, till, moraines, etc.
- Fossil evidence: periodic fluctuations in warm vs. cold water organisms.
- Variations in Oxygen isotopes: $^{18}\text{O}$ evaporates easier than $^{16}\text{O}$ and thus is more enhanced in snow & ice sheets. So $^{18}\text{O}$ enhanced in seashells in ice ages.
- Greenland and Antarctic ice cores show variations in temperature, dust.
- Last ice age was ~20,000 years ago.
- Others at 150,000; 250,000; 350,000...
- Caused by changes in Earth's orbital parameters? (theory...)

An example of some "help"...

The Antarctic Ozone Hole
- 1979
- 1998

Why is Ozone important?
How did this happen?

Will the Climate Change in the Future?

Yes!

- Naturally by fluctuations in Earth's orbital parameters?
- OR
- With a little (or more) help from humans?
- (or both?)

Naturally by fluctuations in Earth's orbital parameters?
- OR
- With a little (or more) help from humans?
- (or both?)
Ozone Layer

- Creation of ozone blocks high energy UV radiation from getting to Earth's surface
- Makes life possible!

The Ozone Layer

- Destruction of ozone allows more UV to get to the surface:
  - Health risks!

The Greenhouse Effect

✓ Some of the infrared (heat) radiation that would normally escape to space is absorbed by certain gases in the Earth's atmosphere
✓ This is the greenhouse effect, responsible for warming the Earth by more than 30°C above its equilibrium temperature
✓ Carbon dioxide (CO₂) and water vapor (H₂O) are Earth's main greenhouse gases
✓ Without the greenhouse effect, we would not be here!
✓ More details Thursday!
**Cosmic Influences on the Biosphere**

- *Impacts* have occurred on Earth
- These catastrophic events appear to have had serious consequences for life on Earth!
  - Severe climate changes: "impact winter"
  - Mass extinctions
  - Probably influenced the origin of life itself!
- Much more detail in next part of the course

**Taking A Global View of the Earth...**

Views of Earth as it could be seen from an extra-terrestrial telescope (hundreds of km resolution)

(Top): Global view of Earth in visible light (left), infrared light (middle), and within a water vapor absorption band (right)

(Right): Global infrared view of Earth from the Galileo spacecraft during an Earth gravity assist flyby

Views of Earth as seen from a low-resolution orbiting satellite platform (tens of km resolution)

Views of Earth as seen from a higher-resolution orbiting satellite platform (a few km resolution)

No obvious signs of life at these scales in the pictures, but there are signs of life detectable in other ways...
Spectroscopy of the Earth...

- Galileo flyby “experiment” described by Sagan in PBD...

We start to see regular, geometric patterns (cities, farms, other structures) at these scales...

Views of Earth as seen from a very high resolution orbiting satellite platform (a few tens of meters resolution)

Views of Earth as seen from an ultra high resolution orbiting satellite or an airborne platform (a few meters resolution)

Summary

- The Earth is a complex rocky planet
  - Differentiated, rocky/metallic interior
  - Large Moon, Strong magnetic field
  - Surface topography is bimodal: oceans, continents
- Crustal rock types:
  - igneous, metamorphic, sedimentary
- Ample evidence of volcanic, tectonic, erosional, and even impact processes on Earth's surface
  - Unique aspect: surface divided into a few dozen moving tectonic plates
Summary

- Earth has a dynamic N₂ & O₂-rich atmosphere
- Earth's volatiles: primordial or externally-derived?
- Weather vs. Climate
- Ozone protects the biosphere against Solar UV
- CO₂ & H₂O are critical greenhouse gases, warming Earth above the freezing point of water
- Climate changes! (Natural vs. Anthropogenic)
  - Ice Ages, Global Warming, Impacts

Next Time...

The Greenhouse Effect

Reading:

- Read through PBD 12
- Skim assignment (A) posted on the web site (Mitchell, 1989)