EAPS 100 – Planet Earth
Prof. L. Braile
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Format: Lecture (PowerPoint, Slides, Videotapes, Quizzes and In-class activities)
Reading in Textbook
3 one-hour exams
Homework
Handouts (next week): Course outline/syllabus.
http://web.ics.purdue.edu/~braile/eas100/eas100home.htm

EAPS 100 – Planet Earth, Requirements:
1) Lectures and Reading in Text (Attendance)
2) Exams (One hour, covering previous ~5 weeks of material, skills, review)
   Midterm (6th week) ~20%
   Midterm (11th week) ~20%
   Final (Final Exam week) ~20%
3) Quizzes and In-class activities (8-10 unannounced) ~10-15%
4) Homework (6-7) ~25-30%
Total points for semester ~525
There is also an online EAPS 100 course, so in any email message, please identify yourself as being in the “lecture”, “T/Th” or “001” EAPS 100 course.

How do points predict final grade?
PRETEST vs. TOTAL POINTS
Pre-Test score is not a good predictor.
\( r = \text{correlation coefficient (1.0 = perfect correlation)} \)
\( r = 0.43 \)

How do points predict final grade?
EXAM II SCORES vs. TOTAL POINTS
As expected, Exam score is a better predictor, but \( r \) is still fairly low.
\( r = 0.71 \)

How do points predict final grade?
Quiz Grades vs. Total Points
The high correlation coefficient means that the performance on quizzes is an excellent predictor of final grade! (Of course, all points are important for final grade.)
\( r = 0.86 \)

How do points predict final grade?
Quiz Scores vs. Total Points
The high correlation coefficient means that the performance on quizzes is an excellent predictor of final grade! (Of course, all points are important for final grade.)
\( r = 0.65 \)
How do points predict final grade?

**Quiz Points vs. Total Points**

It's more than just the 30 points lost by missing 3 quizzes (and it might be only 10 points lost as we drop 2 lowest scores). It reflects a lower performance and learning.

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**Taking notes in class works!**

Note very significant correlation with “taking notes” in class!

**Comparison plot of student study habits and exam scores**

**Attendance shows no correlation!**


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**Student Behavior**

<table>
<thead>
<tr>
<th>Student Behavior</th>
<th>Incoming GPA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;3.5</td>
</tr>
<tr>
<td>Attendance</td>
<td>100%</td>
</tr>
<tr>
<td>Answered Questions</td>
<td>100%</td>
</tr>
<tr>
<td>Answered Questions Correctly</td>
<td>100%</td>
</tr>
<tr>
<td>Noted Confusion</td>
<td>100%</td>
</tr>
<tr>
<td>Volume of Notes</td>
<td>100%</td>
</tr>
</tbody>
</table>

Continued on next slide...

Looking more carefully at additional data on the students in the previous slide (Average Exam Scores vs. Incoming GPA), the table below shows that students with GPA > 3.5 were about 3 times as likely to have Noted Confusion (in their in-class notes), and 4 times as likely to have a substantial Volume of Notes as compared to students with GPA < 3.0!

Why (Geo-) Science???

1. Excellent subject for learning fundamental scientific principles
2. We interact with geoscience every day
3. Importance to future – Energy, climate, environment, natural hazards
4. Scientific literacy – increasingly technological society
5. Increasing awareness and enjoyment of the Earth
6. Science education (for teachers)

Importance of Earth Sciences:

1. Energy (fossil fuels, geothermal, wind, solar, nuclear)
2. Natural Resources (minerals, water, soils, National Parks/recreation)
3. Natural Hazards (earthquakes, tsunami, volcanic eruptions, landslides, hurricanes, tornadoes, floods, asteroids and comet impacts)
4. Environment/Sustainability (climate change, pollution, toxic waste, water quality)
Earth, ocean and atmosphere processes are dynamic. We interact with the Earth, the oceans and the atmosphere every day!

These processes have shaped and changed the solid Earth, oceans and atmosphere over time.

Occasionally, these processes cause sudden, sometimes violent events that we refer to as natural hazards.

Some examples:

Dec. 22, 2013 24-hour radar loop (GMT time).

Aug. 16, 2012 (Thursday) "Shelf" or "Roll" cloud (Lafayette Journal and Courier, Aug. 17, 2012)

U.S. Drought Monitor

California Drought Effects, 2011-2014 (USA Today, 9/3/2014; Oroville is in Northern California)
Shasta Reservoir, 2015

Western U.S. Drought and Wildfires, USA Today, August 9, 2015

Wildfires, USA Today, August 9, 2015

Aug. 24, 2014 M6.0 Napa, California Earthquake (Journal and Courier, 8/25/2014)

Aug. 23, 2011 M5.3 Colorado and M5.9 Central Virginia Earthquakes
Feb. 27, 2010 M8.8 Chile Earthquake – Historical Seismicity

Feb. 27, 2010 M8.8 Chile Earthquake – Cross-Section View

Feb. 27, 2010 M8.8 Chile Earthquake – Seismic Gap

Feb. 27, 2010 M8.8 Chile Earthquake – Gap “Filled” by 2/27/10 event

Feb. 27, 2010 M8.8 Chile Earthquake – Damage to Alto Rio Building, Concepcion, Chile

Feb. 27, 2010 M8.8 Chile Earthquake – Damage to Alto Rio Building, Concepcion, Chile
To report an emergency, call 911. To obtain updates regarding an ongoing emergency, sign up for Purdue Alert text messages, view [www.purdue.edu/alert](http://www.purdue.edu/alert).

There are nearly 300 Emergency Telephones outdoors across campus and in parking garages that connect directly to the PUPD. If you feel threatened or need help, push the button and you will be connected immediately.

If we hear a fire alarm during class we will immediately suspend class, evacuate the building, and proceed outdoors. Do not use the elevator.

If we are notified during class of a Shelter in Place requirement for a tornado warning, we will suspend class and shelter in the basement.

If we are notified during class of a Shelter in Place requirement for a hazardous materials release, or a civil disturbance, including a shooting or other use of weapons, we will suspend class and shelter in the classroom, shutting the door and turning off the lights.


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Emergency Alert: [http://www.purdue.edu/emergency/](http://www.purdue.edu/emergency/)

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At least 20 tornadoes (one EF 3 tornado in Kokomo) in Indiana August 24, 2016 (Lafayette Journal and Courier, Aug. 25, 2016)
A magnitude 6.2 earthquake occurred in a mountainous region in Italy at a depth of 6–10 km. Early reports indicate that 120 people have been killed and many more are trapped under debris.

The earthquake woke residents in Rome, nearly 160 km (100 miles) to the southwest. In the hours following this earthquake, the area continues to experience aftershocks.

The sun rises over collapsed buildings following an earthquake in Amatrice, central Italy, Wednesday, Aug. 24, 2016. A strong earthquake in central Italy reduced three towns to rubble as people slept early Wednesday, with early reports that many were killed and many more injured as rescue crews raced to dig out survivors.

(Massimo Percossi/ANSA via AP)
Aerial view of the church of Santa Maria della Misericordia in Accumoli in central Italy, Aug. 26, 2016, where a strong quake hit early Wednesday. (Photo: Localteam/AP)
Tropical cyclone genesis locations (1851-2009) for August 21-31 (http://www.nhc.noaa.gov/climo/#hrhm)

“Earth-like” planet (Proxima b) discovered orbiting Proxima Centauri, the star nearest to our Sun and “only” 4.2 light years away from us (USA Today, August 25, 2016)

Up to 10 m high tsunami waves hit coastal area near Sendai, in northern Honshu, Japan
Kahului, Maui Tide data, March 9 - 19, 2011 GMT

Tsunami (still propagating through Pacific Ocean ~6 days later)

Max. Amplitude ~2.0 meters

Tsunami Damage from the Tohoku [Northern Honshu, Japan] M9.0 Earthquake of March 11 – Satellite View before Tsunami

Tsunami Damage from the Tohoku [Northern Honshu, Japan] M9.0 Earthquake of March 11 – Satellite View after Tsunami

Winter storm, January 9-10, 2009


Winter storm, Jan. 11-12, 2011 (2 ½-hr loop, 10:00-12:30 GMT Jan. 12, 2011; from intellicast.com)

Sunrise Tippecanoe County Indiana, 6 January 2014. Surface air temperature is -15°F. Optical phenomena produced by flat hexagonal ice crystals or plates, as well as hexagonal pencil crystals consisting of a) solar pillar, produced by reflection of light from “horizontal mirrors” or plates, and b) sun dogs, c) halo, d) upper arc above solar pillar, e) produced by reflection of light from both hexagonal plates and pencil hexagonal crystals. Color spectrum of light is distinctly present in both sun dogs. Photo taken inside shows a window reflection, which is not a part of the solar optical phenomena. (Contributed by E.Agee, Department of Earth, Atmospheric, and Planetary Sciences, Purdue University.)

USA TODAY Snapshots®

Education and earnings

Median earnings in 2000 for workers ages 25 and older by educational level

<table>
<thead>
<tr>
<th>Level of Education</th>
<th>Median Earnings 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bachelor’s degree</td>
<td>$31,400</td>
</tr>
<tr>
<td>Associate degree</td>
<td>$24,400</td>
</tr>
<tr>
<td>Some college, no degree</td>
<td>$22,200</td>
</tr>
<tr>
<td>High school graduate</td>
<td>$20,000</td>
</tr>
<tr>
<td>Some high school</td>
<td>$18,100</td>
</tr>
<tr>
<td>High school graduate</td>
<td>$16,400</td>
</tr>
</tbody>
</table>

Median Earnings vs. Level of Education

12/11/02

USA TODAY Snapshots®

Education and unemployment

Unemployment rates for workers ages 25 and over by education level:

- Master’s degree: 1.6%
- Bachelor’s degree: 1.2%
- Some college, no degree: 3.2%
- High school graduate: 3.5%
- Some high school: 6.5%

Source: Bureau of Labor Statistics, Bureau of the Census
What characteristics did you observe in your sketches?

Lead-in to discussion about what is science and the scientific method

Used to illustrate common stereotype and attempt to adjust their view of science

(This is actually a classic activity that has been used with students of all ages, and adults)

Be sure to hand in your scientist drawing paper (first quiz) with your name clearly written on it – front of room or, on one of two desks by aisles in back of room.

Scientist Drawings – 5th grade students

Scientist Drawings – 5th grade students

Scientist Drawings – 5th grade students

Scientist Drawings – college students
Results

- Scientist drawings:
  - Glasses: 94%; Labcoat: 68%; Pens/Pocket protector: 66%; Bald, weird hair: 56%; Chemistry experiment/test tube, etc.: 36%
  - Male students (college class) drew male scientists 100% of the time; Female students drew male scientists 89% of the time.

- Actual number of female scientists is >30%
- Stereotype (glasses, weird hair or bald, lab coat, male, pens in pocket or pocket protector, chemistry experiment – "the mad scientist" stereotype)
- This stereotype is firmly ingrained in students as young as 2nd grade and does not change!

How is this stereotype formed?

Women with STEM undergraduate degrees in Math, science, engineering and computer science over the past 40 years (USAToday, Oct. 15, 2012)

“Draw a Scientist” Themes

- Chemistry 65%
- Biology/Ecology 15%
- Astronomy 6%
- Computer 6%
- Other 8%
- Earth Science 0%

5th Grade Students

How is science communicated to the public?

Popular movies: Back to the Future, Independence Day
Discussion of scientist drawings

- Reality versus stereotype
- What does this mean about our views of science?
- Interestingly, these views of science and scientists are ingrained in us at a very early age and usually don’t change

So…, what is science?

Science is:

- Description, organization, search for order, quantification of observations (data and experimental results)
- Analytical
- Quantitative
- Constantly changing and being refined
- Conclusions based on observations
- Rational

“Science is a method for testing claims about the natural world, not an immutable compendium of absolute truths.”

-- Stephen Jay Gould

Bully for Brontosaurus, 1991, p. 437

Science is NOT:

- Constant
- Truth
- Based only on belief
- Magic tricks and “flashy” demos

Examples of pseudo-science:

- Astrology
- Almost anything printed in “Enquirer,” “Weekly World News,” “Globe,” “Star,” etc. (grocery store tabloids)
Metric! Metric! Metric!

Why Metric?
A. The metric system is much easier. All metric units are related by factors of 10.
B. Nearly the entire world (95%), except the United States, now uses the metric system. U.S. economic competitiveness would be strengthened by converting to the metric system.
C. Metric is used exclusively in science – therefore, understanding of scientific and technical issues by non-scientists will be enhanced if the metric system is universally adopted.
D. Because the metric system uses units related by factors of ten and the types of units (distance, area, volume, mass) are simply-related, performing calculations with the metric system is much easier thus facilitating quantitative analysis and understanding in science. That is, mathematical manipulations using the metric system are easier which leads to fewer mistakes and less confusion and increases the chance that scientific principles and concepts can be understood!
RESEARCH ON LEARNING CATEGORIES –
How much we retain after one year

1. Attitudes  100%
2. Thinking skills and processes  80%
3. Motor skills  70%
4. Concepts  50%
5. Factual material  35%
6. Nonsense syllables  10%

WE LEARN AND RETAIN

10% of What We Hear
15% of What We See
20% of What We Both See and Hear
40% of What We Discuss With Others
80% of What We Experience Directly or Practice
90% of What We Attempt to Teach Others

SCHOOL OF EDUCATION

Scale
(actual size / model size = scale factor,
usually expressed as 1:1 million, for example)

Importance of SCALE
Significance and understanding of large and small quantities in the geosciences:

Distance scales:
$10^{-15}$ to $10^{25}$ meters

Time scales:
$10^{-6}$ to 15 billion years
$(1.5 \times 10^{10}$ years$)$

Various Scales
(actual size/model size = scale factor)
Model Car – so, for the model car, an actual car is about 5 m long and the model car is about 15 cm long, so $450 \text{ cm}/15 \text{ cm} = 30$ (notice that the units cancel)
Dinosaur
State Map
Globe
Solar System

Various Scales
(actual size/model size = scale factor)
Model Car 1:30
Dinosaur 1:50
State Map 1:1 million
Globe 1:40 million
Solar System 1:1 billion
Typical roadmap of the state of Indiana (such as one you would carry in a vehicle) would have a height of about 0.5 meters. The true N-S distance of the state is almost 500 km, so the map scale is about 1:1 million (500 km/0.5 m).

Various Scales (actual/model size = scale factor)

Globe: Typical diameter is ~30 cm. Earth diameter is ~13,000 km. So scale is 13,000 km or 13,000,000 m divided by 30 cm or 0.30 m. Now the meters cancel, so the scale factor is ~40 million and the scale is written as 1:40 million.

Sun and Earth at 1:1 billion Scale

D = 1.39 m

Checking scale....
150 m x 1 billion (10^9)
= 150 x 10^6 m
= 150 x 10^4 km
= 150 million km!
(93 million miles)

How much is a billion???

(1 billion = 10^9)

How many is a Billion?
Counting to a billion – or, “a billion seconds”

<table>
<thead>
<tr>
<th>1</th>
<th>One</th>
<th>10^9</th>
<th>1 second</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td>10^8</td>
<td>10 seconds</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>10^7</td>
<td>1.67 minutes</td>
</tr>
<tr>
<td>1,000</td>
<td>Thousand</td>
<td>10^6</td>
<td>16.67 minutes</td>
</tr>
<tr>
<td>10,000</td>
<td></td>
<td>10^5</td>
<td>2.78 hours</td>
</tr>
<tr>
<td>100,000</td>
<td></td>
<td>10^4</td>
<td>1.16 days</td>
</tr>
<tr>
<td>1,000,000</td>
<td>Million</td>
<td>10^3</td>
<td>11.57 days</td>
</tr>
<tr>
<td>10,000,000</td>
<td></td>
<td>10^2</td>
<td>3.17 years</td>
</tr>
<tr>
<td>100,000,000</td>
<td></td>
<td>10^1</td>
<td>31.7 years</td>
</tr>
</tbody>
</table>
How fast is Earth moving through space?

1. Revolution (orbit)

Distance = \( \pi d \) (circumference)

= 3.14 \times 2 \times 150 \text{ million km} \\
\sim 9 \times 10^8 \text{ km} \\
(\text{almost 1 billion km in one year})

Velocity = \( \frac{9 \times 10^8 \text{ km}}{365 \text{ days}} \times \frac{24 \text{ hrs}}{365 \text{ days}} \) \\
\sim 100,000 \text{ km/hr} \\
\sim 30 \text{ km/s (0.001% of the speed of light)}

2. Rotation (about axis; at equator)

Circumference = \( \pi d \) = \sim 6000 \text{ km} \times 2 \times 3.14 \\
\sim 40,000 \text{ km}

Velocity = \( \frac{40,000 \text{ km}}{24 \text{ hrs}} \) \\
\sim 1700 \text{ km/hr} \\
\sim 0.5 \text{ km/s}

Visualizing very large numbers

If you had Avogadro’s number* (6.022 X 10^{23}) of un-popped popcorn kernels, and spread them across the United States of America, the country would be covered in popcorn to a depth of about 15 km (http://www.uky.edu/~garose/avogadro).

*The mole is the unit of measurement in the International System of Units (SI) for amount of substance. It is defined as the amount of a chemical substance that contains as many elementary entities—e.g., atoms, molecules, ions, electrons, or photons, as there are atoms in 12 grams of carbon-12 (12C), the isotope of carbon with relative atomic mass 12 by definition. This number is expressed by the Avogadro constant, which has a value of 6.022140857(74)\times10^{23} \text{ mol}^{-1}. The mole is one of the base units of the SI, and has the unit symbol mol. (https://en.wikipedia.org/wiki/Mole_%28unit%29)
“Powers of Ten” video:
Illustrates vast scale of the universe by viewing scenes (pictures or simulated images from progressively greater distances – each view is ten times as far away as the previous view and, therefore, shows an image ten times as wide (1m, 10m, 100m, 1 km, 10 km, 100 km …) through over 40 powers of ten from the subatomic scale to the scale of the universe. The film provides a useful illustration of distances and the relative sizes of objects in the universe.

http://www.youtube.com/watch?v=0fKBhvDljuy0

- Can image 30th magnitude objects.
- Required 400 orbits, 11.3 days or recording.
- Image contains about 10,000 galaxies.
- Area covers 1/12.7 million of the entire sky.
- Like looking through an 2 ½ m (8 ft) long soda straw. With this view, astronomers would need about 50 Ultra Deep Fields to cover the entire Moon.
- Hubble’s keen vision (0.085 arc seconds) is equivalent to standing at the U.S. Capitol and seeing the date on a quarter 400 m (1/4 mile) away at the Washington monument.
Important concepts for today:

- Forces and Energy (four types of forces; density (mass/volume so gravity is involved)
- Sources of energy
- Energy conversion
- Thermodynamics
### Density Samples:

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>≈ 0.001</td>
</tr>
<tr>
<td>Styrofoam</td>
<td>≈ 0.01</td>
</tr>
<tr>
<td>Wood</td>
<td>≈ 0.5 – 1.0</td>
</tr>
<tr>
<td>Water</td>
<td>1.0 (1 g water = 1 ml = 1 cm³)</td>
</tr>
<tr>
<td>Typical surface rocks</td>
<td>≈ 2.0 – 2.8</td>
</tr>
<tr>
<td>Earth’s mantle (olivine)</td>
<td>≈ 3.3</td>
</tr>
<tr>
<td>Pyrite</td>
<td>≈ 5.5</td>
</tr>
<tr>
<td>Iron</td>
<td>≈ 5.5</td>
</tr>
<tr>
<td>Lead</td>
<td>≈ 8.0</td>
</tr>
<tr>
<td>Gold</td>
<td>≈ 20</td>
</tr>
</tbody>
</table>

### Forces (4 types):
- **Strong force**
- **Weak force**
- **Electromagnetic force**
- **Gravity**

(Gravity equation involves mass, and density = \( \text{mass} / \text{volume} \), so materials, rocks, of differing densities will be affected differently by **GRAVITY**)

### Density  
\[ \text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{m}{v} \]  
(mass per unit volume; usually given in g/cm³)  
Density of water = 1.0 g/cm³

For styrofoam block:

\[ v = 5 \times 10 \times 8 = 400 \text{ cm}^3 \]  
(0.4 Liter)

\[ m = 4 \text{ g} \]  
Density = \( \frac{4}{400} = 0.01 \text{ g/cm}^3 \)

Gravitational attraction – Sun and Earth  
Fig. 15.16, Text

Gravity controls the orbits of planets resulting in precise relationships.

The Solar System (not to scale)  
Fig. 15.17, Text

(Gravity equation involves mass, and density = \( \text{mass} / \text{volume} \), so materials, rocks, of differing densities will be affected differently by **GRAVITY**)

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\[ v = 5 \times 10 \times 8 = 400 \text{ cm}^3 \]  
(0.4 Liter)

\[ m = 4 \text{ g} \]  
Density = \( \frac{4}{400} = 0.01 \text{ g/cm}^3 \)
**Electromagnetic [EM] Spectrum/Energy/Radiation**

![Schematic illustration of wavelengths of EM energy change in wavelength from short to long is much, much greater than illustrated here.]

**Sources of Energy (Heat)**
1. Gravitational (impacts during accretion of Earth, mass movements due to density variations)
2. Solar Radiation [EM] (atmosphere and oceans)
3. Nuclear – Radioactivity (note two different meanings of the term radiation)

**Energy Transfer**
1. Radiation (radiating) [EM]
2. Conduction
3. Convection

**Energy Conversion**
1. Gravitational (kinetic) to Heat
2. Thermodynamics (Pressure-Temperature)
3. Energy – Mass \( E = mc^2 \)

**Thermodynamics:**
- Equilibrium of pressure and temperature effects in mechanical interactions (work)
- Follows from Conservation of Energy
- Adiabatic Effects (process in which no heat is added or subtracted — temperature changes are caused by changes in pressure):
  - increase pressure \( \Rightarrow \) temperature increases
  - decrease pressure \( \Rightarrow \) temperature decreases
- (example: releasing air from a tire, refrigeration, air conditioning)

**Example of Thermodynamic Effect – Adiabatic Heating and Cooling**
- Volume of Air
  - Add Pressure (Energy)
  - Molecules (vibrating and interacting)
- Volume decreases \( \Rightarrow \) Temperature increases
- Volume increases \( \Rightarrow \) Temperature decreases
Important concepts for today:

- Radioactive decay; Half-life
- Radiometric Dating
- Geologic Time

The Geological Time Scale (see Figure 8.23, text)

Geologic Time Scale: (see Figure 8.23, text) – rock age originally described by name based on locations (i.e. Cambria and Devon in England) of distinctive layers that could be observed or correlated (see Figure 8.15 and 8.17, text) over long distances. After radiometric age dating was developed, absolute ages have been determined for the geologic ages. A simplified geologic time scale (useful for our purposes, and easy to remember) is:

- Cenozoic (“young life”) 0 to 65 mya*
- Mesozoic (“middle life”) 65 to 251 mya
- Paleozoic (“old life”) 251 to 542 mya
- Precambrian** 542 to 4500 mya

* mya = millions of years ago

** Precambrian is the name used for the vast time period before the Cambrian which is the oldest major time unit of the Paleozoic

Half-Lives of Some Useful Radioactive Isotopes (also, Table 8.1, text)

<table>
<thead>
<tr>
<th>Radioactive Parent</th>
<th>Stable Daughter Product</th>
<th>Half-Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon – 14</td>
<td>Nitrogen – 14</td>
<td>5730 yrs</td>
</tr>
<tr>
<td>Potassium – 40</td>
<td>Argon – 40</td>
<td>1.3 Billion</td>
</tr>
<tr>
<td>Uranium – 238</td>
<td>Lead – 206</td>
<td>4.5 Billion</td>
</tr>
<tr>
<td>Thorium – 232</td>
<td>Lead – 208</td>
<td>14.1 Billion</td>
</tr>
<tr>
<td>Uranium – 235</td>
<td>Lead – 207</td>
<td>713 million</td>
</tr>
<tr>
<td>Rubidium – 87</td>
<td>Strontium – 87</td>
<td>4.7 Billion</td>
</tr>
</tbody>
</table>

half-life = the time for 50% of the parent material to decay

Important concepts for today:

- Radioactive decay; Half-life
- Radiometric Dating
- Uniformitarianism (Uniformity)
- Examples: Glaciations (ice ages); Asteroid, meteor and comet impact
Geologic Time/Age of the Earth

1. Observations:
   - Oldest rocks on Earth ~ 4.1+ billion years
   - Almost all meteorites ~ 4.5 billion years

2. Age Dating Methods:
   a. Relative age
      - Rates of processes – erosion, deposition, cooling of Earth, accumulation of salt in the oceans
   b. Superposition – for layered rocks deposited on the surface, oldest rocks are on the bottom
   c. Fossils – correlation of rocks with distinctive “index fossils”
   d. Cross-cutting relationships (see figure; also Figures 8.5, 8.6, 8.13, text)

Iron-Nickel Meteorite (Radiometric age dating of meteorites results in consistent age determinations of ~4.5-4.6 billion years)
Superposition of sedimentary layers

Figure 8.2, text.

**b. Absolute methods**
- Rates of processes (when calibrated)
- Fossils – when age of index fossils (exist over only a short time duration, but are widely distributed) are known
- Radiometric dating (most important) based on spontaneous decay of isotopes (radioactivity) at constant rates (see Figure 8.20, text); examples:

Uranium$^{238}$ to Lead$^{206}$
Potassium$^{40}$ to Argon$^{40}$
Carbon$^{14}$ to Nitrogen$^{14}$

Rate described by:

Half-life = the time for 50% of the parent material to decay

Production and decay of Carbon-14 (Figure 8.21, text)

Illustration of the meaning of half life for a radioactive isotope ($^{14}$C parent, $^{14}$N daughter product) with a half life of 5700 years

<table>
<thead>
<tr>
<th>Half Lives</th>
<th>Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100 % Parent (Radioactive) Isotopes</td>
</tr>
</tbody>
</table>

When the tree dies, falls down and is buried by sediments, it has a fixed amount of $^{14}$C (we'll call it 100% for simplicity) and no longer interacts with its surroundings in the same way. This amount is shown by the partial bar graph above. Now the $^{14}$C in the tree begins to radioactively decay and is not replenished from its surroundings.

Illustration of the meaning of half life for a radioactive isotope ($^{14}$C) with a half life of 5700 years

<table>
<thead>
<tr>
<th>Half Lives</th>
<th>Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100 % Parent (radioactive) Isotopes</td>
</tr>
<tr>
<td>1</td>
<td>50% remaining</td>
</tr>
</tbody>
</table>

After one half life (~5700 years for $^{14}$C), there is 50% of the original $^{14}$C remaining.
Half Lives

<table>
<thead>
<tr>
<th>Half Lives</th>
<th>100 % Parent Isotopes</th>
<th>Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>50% remaining</td>
<td>5700</td>
</tr>
<tr>
<td>2</td>
<td>25%</td>
<td>11,400</td>
</tr>
</tbody>
</table>

After two half lives (~11,400 years for 14C), there is 25% of the original 14C remaining. Because the number of 14C isotopes has decreased, the number that decay in our sample in the second half life is less even though the rate of decay remains a constant.

Half Lives

<table>
<thead>
<tr>
<th>Half Lives</th>
<th>100 % Parent Isotopes</th>
<th>Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>50% remaining</td>
<td>5700</td>
</tr>
<tr>
<td>2</td>
<td>25%</td>
<td>11,400</td>
</tr>
<tr>
<td>3</td>
<td>12.5%</td>
<td>17,100</td>
</tr>
</tbody>
</table>

After three half lives, there is 12.5% of the original 14C remaining.

Half Lives

<table>
<thead>
<tr>
<th>Half Lives</th>
<th>100 % Parent Isotopes</th>
<th>Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>50% remaining</td>
<td>5700</td>
</tr>
<tr>
<td>2</td>
<td>25%</td>
<td>11,400</td>
</tr>
<tr>
<td>3</td>
<td>12.5%</td>
<td>17,100</td>
</tr>
<tr>
<td>4</td>
<td>6.25%</td>
<td>22,800</td>
</tr>
</tbody>
</table>

After four half lives, there is only 6.25% of the original 14C.

Note that this is an exponential decay, so the % of parent (still radioactive) isotopes decreases rapidly with time, so the curve (blue line) approaches zero after many half lives.

So, after many half lives (say 10 to 15), there is so little parent material remaining that it cannot be measured accurately. For the 14C method, this is about 70,000 years (due to the short half life of 14C). For other isotopes (used for rocks, much longer half lives), age dating can extend back millions or billions of years.

To use the 14C radiometric age dating method, we collect a sample of an organic material, such as part of the dead and buried tree, and measure the amount of 14C remaining (relative to the amount it had when alive). For example, if there is 12.5% of the 14C parent material remaining (and 87.5% of the 14C has decayed into the daughter product 14N), then the age of the sample is 3 half lives or ~17,100 years old.
Explanation of radioactive decay, half-life and radiometric age dating (Figure 8.20, text)

The basic concepts of radiometric dating (the exponential decay and the generally constant-over-time half-life of isotopes) have been verified by laboratory measurements and comparisons of age dates using different isotopes.

For the carbon 14 method, accuracy of the method has been verified by comparison with other dating methods such as: comparison with yearly layering (can just be counted) in ice cores, glacial and ocean sediments, corals; and tree ring chronologies. The radiometric ages (from other, longer half-life isotopes) are also consistent with worldwide measurements of plate velocities that can be accurately measured.

The Grand Canyon has one of the best exposures of rocks that extend over ~2 billion years in age. (Figure 8.15, text)

Grand Canyon rock layers

See Figures 8.15 in text.

Also see Figure 8.14, text.
Some fossils are *index fossils* (widespread, distinctive, limited age range) and provide accurate age information for geologic units.

Orthoceras, Paleozoic-Early Mesozoic fossil

Uniformitarianism (uniformity):

- Analogous to: “Laws of physics are constant”
- “The present is the key to the past”
- By studying modern geologic processes, we can *infer* past events when we *observe* the results of those processes displayed in the geologic record - examples: volcanic deposits, sediments in shape of delta, offset of layers by faulting due to an earthquake
- Earth is shaped by slow, continuous processes acting over geologic time

The Grand Canyon has one of the best exposures of rocks that extend over ~2 billion years in age.
Columbia river basalt flows (~16 million years old)


Note layers of basalt lava, erupted on the surface, so youngest above and oldest below (superposition). The canyon is younger than the rock units (cross-cutting relationship).

Catastrophism:
- Earth is shaped by sudden, occasional, catastrophic events
  (some events are “once-only” or very rare so are often thought of as catastrophic - -
  examples:
  - - differentiation of Earth (crust, mantle, core)
  - - development of atmosphere, oceans, life
  - - asteroid/comet impacts)
- Modified principle (mostly applied to evolution of species through time) is “Punctuated Equilibrium”

Glaciation - - an example of application of the concept of uniformitarianism (Louis Agassiz, ≈ 1850)
- In modern glaciers and glacial terrane, we observe distinct features (striations, deposits [till], moraines, drumlins, U-shaped valleys, erratics, etc.)
- Recognition of these features in the geologic record (ancient deposits and landforms, etc.) allows inference of previous glaciations or “ice ages”
Alpine (mountain) glacier – “A river of ice”

A U-shaped valley results after melting of alpine glaciers (Yosemite valley is a good example)

Striations (scratches) and polished rock surfaces indicate glacial ice movement

Striations (Crater Lake, Oregon), also see Figure 4.11, text.

Erratic

Glacial till (deposited directly by glacial ice; not mix of sediment sizes)

Drumlins (streamlined hills)

Figure 4.15, text.

Figure 4.12, text.

Figure 4.19, text.

Figure 4.7, text.

Figure 4.11, text.

Figure 4.16, text.
Antarctic ice sheet, profile location (A-B) and cross-section, below.

Cross-section view (like slicing through a layer cake) through the Antarctic ice sheet – note that the ice sheet is about 3 km thick near the South Pole.

Cross-section (like slicing through a layer cake) through the Antarctic ice sheet. (Vertical exaggeration makes slopes look greater than they actually are)

Maximum extent of continental glaciers (ice sheets), Northern hemisphere, last ice age (~20,000 years ago). (Figure 4.24, text)

Comparison of coastlines: past (~18,000 years ago), present, and future (?) if ice sheets melt.

Also see Figure 4.18 and 4.22, Lutgens and Tarbuck, 2017.
Shoemaker-Levy 9 comet after breaking up into about 21 pieces. First discovered on March 24 of 1993, the chain of comets sometimes called “string of pearls,” had been orbiting Jupiter for about 20-30 years. It apparently broke into fragments about July of 1992 and then collided with Jupiter beginning on July 16 to July 22, 1994 with a speed of about 60 km/s (~200,000 km/hr).


The planet Jupiter after Shoemaker-Levy 9 comets collided with the planet. The small dark spot near the top of the image is one of Jupiter’s moons. The larger impact effects are larger than the size of the Earth.

A chain of craters on Ganymede (one of Jupiter’s moons), probably caused by a chain of comets or asteroids similar to (but smaller than) the Shoemaker-Levy 9 impact events. The picture covers an area approximately 190 km across.


Orbits of Potentially Hazardous Asteroids (August 14, 2013)
Image Credit: NASA, JPL-Caltech
Photographic time exposure through a telescope. White streaks are stars. The apparent motion is due to the Earth's rotation during the time exposure. The asteroid (~300 m in size), discovered in this image, has a very different apparent motion because it is much, much closer to the Earth.

(National Geographic, 2008)
Asteroid Eros

Manicouagan Crater, eastern Quebec, Canada, ~100 km diameter

Kondyor Crater, Siberia (mining for titanium and other metals)

Chicxulub Crater (Yucatan Peninsula) Gravity Field
Crater is about 200 km in diameter

Meteor crater event about every few tens of thousands of years.

Chicxulub crater event about every 100 million years.

Apollo 17 landing site – Note scale and large numbers of craters.
Explanation: This view of the Apollo 17 landing site in the Taurus-Littrow valley was captured last month by the Lunar Reconnaissance Orbiter (LRO), the sharpest ever recorded from space. The high-resolution image data was taken during a period when LRO's orbit was modified to create a close approach of about 22 kilometers as it passed over some of the Apollo landing sites. That altitude corresponds to only about twice the height of a commercial airline flight over planet Earth. Labeled in this image are Apollo 17 lunar lander Challenger’s descent stage (inset), the lunar rover (LRV) at its final parking spot, and the Apollo Lunar Surface Experiments Package (ALSEP) left to monitor the Moon's environment and interior. Clear, dual lunar rover tracks and the foot trails left by astronauts Eugene Cernan and Harrison Schmitt, the last to walk on the lunar surface, are also easily visible at the Apollo 17 site.

http://apod.nasa.gov/apod/ap110908.html

New Martian impact crater – photo taken Nov. 19, 2013

“A dramatic, fresh impact crater dominates this image taken by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA’s Mars Reconnaissance Orbiter on Nov. 19, 2013. Researchers used HiRISE to examine this site because the orbiter’s Context Camera had revealed a change in appearance here between observations in July 2010 and May 2012, bracketing the formation of the crater between those observations.”

“The crater spans approximately 100 feet (30 meters) in diameter and is surrounded by a large, rayed blast zone. Because the terrain where the crater formed is dusty, the fresh crater appears blue in the enhanced color of the image, due to removal of the reddish dust in that area. Debris tossed outward during the formation of the crater is called ejecta. In examining ejecta’s distribution, scientists can learn more about the impact event. The explosion that excavated this crater threw ejecta as far as 9.3 miles (15 kilometers).”

Hurricane Harvey – August 25-29, 2017

Table 14.3 Saffir-Simpson Hurricane Scale

<table>
<thead>
<tr>
<th>Scale Number (category)</th>
<th>Central Pressure (millibars)</th>
<th>Winds (km/hr)</th>
<th>Storm Surge (meters)</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;980</td>
<td>119-153</td>
<td>1.2-1.5</td>
<td>Minimal</td>
</tr>
<tr>
<td>2</td>
<td>965-979</td>
<td>154-177</td>
<td>1.6-2.4</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>945-964</td>
<td>178-209</td>
<td>2.5-3.6</td>
<td>Extensive</td>
</tr>
<tr>
<td>4</td>
<td>920-944</td>
<td>210-250</td>
<td>3.7-5.4</td>
<td>Extreme</td>
</tr>
<tr>
<td>5</td>
<td>&lt;920</td>
<td>&gt;250</td>
<td>&gt;5.4</td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

Table 14.2 L&T, 2017

Hurricane Harvey is “fiercest” hurricane in the U.S. in 13 years and the strongest hurricane in Texas since Carla in 1961 (also note the famous Galveston hurricane of 1900, and Katrina in 2005, almost exactly 12 years ago).
Note logarithmic scale. Also, the graph shows size of the event (discharge in cubic feet per second) versus frequency of occurrence (return period in years). Similar relationships are found for other hazards such as earthquakes, volcanic eruptions, hurricanes, tornadoes and other natural hazards!

Flood frequency versus discharge graph for the Wabash River near Lafayette, IN (https://serc.carleton.edu/hydromodules/steps/168500.html)

Hurricane Harvey from the International Space Station

Hurricane Harvey, Category 4, Radar, Friday, August 25, 2017, 11:15 a.m. – 1:15 p.m. EDT. (intellicast.com)

Hurricane Harvey, Category 4, Radar, Friday, August 25, 2017, 11:30 a.m. – 1:30 p.m. EDT. (intellicast.com)

Hurricane Harvey, Category 2, Radar, Saturday, August 26, 2017, 7:45 – 10:45 a.m. EDT. (intellicast.com)

Hurricane Harvey, Category 1, Radar, Saturday, August 26, 2017, 1:45 – 3:45 p.m. EDT. (intellicast.com)
Hurricane Harvey, Infrared Satellite Image, Monday, August 28, 2017, 11:15 a.m. EDT. (intellicast.com)

A somewhat similar storm - Tropical Storm Allison (2001) Flood Map for Harris County

Tropical Storm Allison (2001) Flood Map
FEMA 100-Year Flood Zones
Flooded Structure Within FEMA 100-Year Zone
Flooded Structure Outside FEMA 100-Year Zone

https://projects.propublica.org/graphics/harvey

Rainfall by Monday, August 28


flooding, impact; so far (likely to change), the loss of life has been small.

Harvey – “flat” topography and very slow storm movement contribute to flooding hazard!

http://nypost.com/2017/08/27/dramatic-before-and-after-
photos-show-surreal-flooding-in-texas/


47 feet
50 feet
50 feet

Before & After: Flooding on Buffalo Bayou in Houston

Before & After: Flooding on Buffalo Bayou in Houston

MORE VIDEOS

http://nypost.com/2017/08/27/dramatic-before-and-after-
photos-show-surreal-flooding-in-texas/
Jan. 23, 2017,
https://www.washingtonpost.com/graphics/2017/national/harvey-photos-before-

Tuesday, Aug. 30, 2017,
https://www.washingtonpost.com/graphics/2017/national/harvey-photos-before-after/?utm_term=.8ac756de9ec0
NOTE: The hurricane Harvey and Hurricane Irma slides shown here are for your interest as we discussed these in class in the early part of the semester. As we will be covering hurricanes later in the semester, hurricane information will not be included in Exam 1.
Historically more storms hit Florida than any other U.S. state

Hurricane Irma

Comparison of the size of Hurricanes Andrew (1992, upper) and Irma (2017, lower)

2017 Atlantic hurricane season through 9 September 2017, at 10:25 GMT.


https://en.wikipedia.org/wiki/2017_Atlantic_hurricane_season#/media/File:2017_Atlantic_hurricane_season_summary_map.png

https://www.theguardian.com/world/2017/sep/07/where-
### Atlantic Tropical Storms History

<table>
<thead>
<tr>
<th>Name</th>
<th>Dates active</th>
<th>Storm category at peak intensity</th>
<th>Max 1-min wind mph (km/h)</th>
<th>Min.press. (mbar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arlene</td>
<td>April 19 – 21</td>
<td>Tropical storm</td>
<td>50 (85)</td>
<td>990</td>
</tr>
<tr>
<td>Bret</td>
<td>June 19 – 20</td>
<td>Tropical storm</td>
<td>45 (75)</td>
<td>1007</td>
</tr>
<tr>
<td>Cindy</td>
<td>June 20 – 23</td>
<td>Tropical storm</td>
<td>60 (95)</td>
<td>992</td>
</tr>
<tr>
<td>Four</td>
<td>July 6 – 7</td>
<td>Tropical depression</td>
<td>30 (45)</td>
<td>1008</td>
</tr>
<tr>
<td>Don</td>
<td>July 17 – 19</td>
<td>Tropical storm</td>
<td>50 (85)</td>
<td>1007</td>
</tr>
<tr>
<td>Emily</td>
<td>July 31 – August 2</td>
<td>Tropical storm</td>
<td>45 (75)</td>
<td>1005</td>
</tr>
<tr>
<td>Franklin/August 7 – 10</td>
<td>Cat. 1 hurricane</td>
<td>85 (140)</td>
<td>981</td>
<td></td>
</tr>
<tr>
<td>Gert</td>
<td>August 13 – 17</td>
<td>Cat. 2 hurricane</td>
<td>105 (165)</td>
<td>967</td>
</tr>
<tr>
<td>Harvey</td>
<td>Aug. 17 – Sept. 1</td>
<td>Cat. 4 hurricane</td>
<td>130 (215)</td>
<td>938</td>
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<tr>
<td>Irma</td>
<td>Aug. 30 – Present</td>
<td>Cat. 5 hurricane</td>
<td>155 (250)</td>
<td>914</td>
</tr>
<tr>
<td>Jose</td>
<td>Sept. 5 – Present</td>
<td>Cat. 4 hurricane</td>
<td>155 (250)</td>
<td>938</td>
</tr>
<tr>
<td>Katia</td>
<td>Sept. 5 – Present</td>
<td>Cat. 2 hurricane</td>
<td>105 (165)</td>
<td>972</td>
</tr>
</tbody>
</table>

2017 Atlantic hurricane season (June 1-November 30) through 9 September 2017, at 10:25 GMT.  
(https://en.wikipedia.org/wiki/2017_Atlantic_hurricane_season)

#### Atlantic Tropical Storm Season Forecasts 2017*

<table>
<thead>
<tr>
<th>Source</th>
<th>Named Storms</th>
<th>Hurricanes</th>
<th>Hurr. (Cat. 3+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSR</td>
<td>11</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>CSU</td>
<td>11</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>TWC</td>
<td>12</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>NOAA</td>
<td>11-17</td>
<td>5-9</td>
<td>2-4</td>
</tr>
</tbody>
</table>

* April, 2017 except for NOAA, May, 2017

https://en.wikipedia.org/wiki/2017_Atlantic_hurricane_season

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**EAPS 100 – Planet Earth**  
Prof. L. Braile  
2271 HAMP (CIVL), braile@purdue.edu

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