

Suggested Study Habits

Science usually advances by building on previous work:

“If I have seen farther than other men, it is because I have stood upon the shoulders of giants”

–Newton

Just as in science in the real world, in this class we will often draw upon concepts encountered earlier.

Important to keep up!

Come to class

However, I shouldn't be your sole source of information.

Read the assigned material *before* class.

Don't expect to understand everything, but note points about which you are unsure.

You will then have a better idea about what to look for in class.

Read the assigned material again *after* class.

Copies of my transparencies are (or will be) available in the library and on their web site.

However, you should *NOT* consider them a replacement for your own notes—take notes!

This is a *college* level course—standards will be higher than high school.

You should expect to spend about 2 hours outside class for each hour in class on this course.

I (and I hope you) expect more for you out of this course than just the ability to regurgitate facts.

For example:

Factual: Mt. Ranier is a stratovolcano.

Conceptual: Why? What geologic processes lead to it being a stratovolcano? Why do stratovolcanoes look and behave the way they do?

Do not struggle in silence.

Form study groups, use each other as resources.

If you are having trouble, please come to see me.

That is what office hours are for!

Better to seek help sooner rather than later.

Teacher Expectations

Expect me to come and start class on time.

Expect me to treat you with respect.

Expect me to maintain order in the classroom.

Expect me to get your papers back within a week.

Expect me to answer your e-mails and phone messages within 24 hours (except on weekends).

Student Expectations

Come to class on time.

Come to class prepared:

—Do the reading ahead of time.

—Be prepared to begin class on time.

Participate in class.

Treat me and others with respect.

Maintain order in the classroom.

Why Study Geology?

Mitigate natural disasters:

Earthquakes:

On Oct. 17, 1989 a 7.1 earthquake occurred near Santa Cruz, CA killing 62 people

On Jan. 17, 1994 a 6.7 earthquake occurred in Northridge, CA killing 72 people

On February 28, 2001 a 6.8 earthquake hit near Olympia, yet only 1 person died (heart attack).

On Aug. 17, 1999 a 7.4 earthquake hit near Izmit, Turkey killing 17,000+

On Dec. 26, 2003 a 6.6 earthquake hit Bam, Iran, with a death toll estimated at about 30,000

Why the discrepancy?

On Jan. 25, 1999 a 5.8 earthquake hit Colombia killing 1,185.

Why?

Volcanic Eruptions:

Mt. Pinatubo eruption wiped out entire towns.

Yet nobody was killed by the eruption! Why not?

Floods:

Alas, many people like to live on flood plains.

Study of geology can help us to understand the risk.

Resource Extraction:

We live in a material world.

Examples?

Environmental Impact:

Expansion of SFO

Beach erosion

Overview of the Earth

Mass: 5.98×10^{24} kg

Radius: 6370 km

Density: 5.5 g/cm^3

Note that the density of water is 1.0 g/cm^3 .

Most rocks have a density around $\sim 3 \text{ g/cm}^3$.

What does the density of the Earth tell us about the interior of the planet?

In addition to the compositional units, the region near the surface forms distinct mechanical units.

The rock near the surface is rigid and is called the *lithosphere*.

Consists of the crust and upper mantle.

Increased pressure and temperature below the lithosphere leads to a region of relatively soft rock.

This region is called the *asthenosphere*.

Surface of the Earth

The oceanic crust and continental crust are quite distinct:

Different composition:

Thickness:

Different ages:

Historical Development of Geology

Prior to the 19th century it was commonly believed that the Earth evolved through short-lived violent events.

Between these events were quiescent times during which little evolution took place.

This widely accepted theory at the time is known as *catastrophism*.

For example, catastrophists believed that mountains were born when violent eruptions resulted in a huge uplift of rocks out of the ocean depths.

They would have argued that the Grand Canyon must have been formed by a violent tearing and wrenching of the Earth's surface.

In contrast, we now believe that most mountains rise slowly over time.

The Grand Canyon was cut over millions of years of erosion by the Colorado river.

Why did catastrophism take hold in the 1700s?

Our view changes—James Hutton

James Hutton was the first person to significantly challenge the prevailing view of the Earth.

He realized that slow processes such as rivers slowly eroding their beds or the slow erosion of rocks by winds, water, sunlight was occurring.

Given enough time such processes could lead to significant evolution of the Earth's surface.

However, if so, the Earth must be much older than people thought.

These concepts gave rise to the idea of *Uniformitarianism*.

The basic tenet of uniformitarianism is that the processes shaping the Earth's surface today are the same ones which shaped it in the past.

“the present is the key to the past”

Hutton published his thoughts in a paper published in 1788.

However, his ideas were resisted at first.

Why?

However, his ideas eventually won out over catastrophism, helped by the publication of other works:

1802, Playfair published *Illustrations of the Huttonian Theory*

In 1830 Sir Charles Lyell published his book *Principles of Geology*

This book expanded on Hutton's ideas and laid the groundwork for the development of modern geology.

While most geologists believe in uniformitarianism today, they realize that catastrophic events do occur as well.

Sometimes volcanic eruptions do lead to the violent buildup of mountains.

Much of the erosion caused by rivers does occur during relatively brief floods.

Major earthquakes can lead to shifts of several meters in a single moment.

Catastrophic resurfacing of Venus?

Origin of the Moon.

The Scientific Method

1. Take observations—look for patterns
 - a. Classification
2. Develop an hypothesis (or more) which can explain the observations.
3. Make predictions based on the hypothesis.
4. Design and carry out experiments or observations to check the predictions made.

5. Compare results to the hypothesis:
 - a. If the predictions are borne out it strengthens our belief in the hypothesis.
 - b. If predictions are not borne out the hypothesis needs to be abandoned or modified. Back to the drawing board!

Implicit assumptions:

The Universe follows a set of rules.

Divine intervention is not allowed!

However, it seems to work pretty well!

The Scientific Method in Action:

Origin of the Moon

Initial observations:

The Earth - Moon system is very unusual.

Other terrestrial planets do not have satellites like our Moon.

The Moon is very large compared to its primary.

Suggests the Moon may not have formed like other satellites in the Solar System.

How might it have formed?

Hypotheses for the Formation of the Moon

Three main hypotheses:

1. Moon formed along with the Earth.

2. Moon formed elsewhere in the Solar System and was later captured by the Earth.

3. Earth formed first then the Moon either knocked off the Earth or thrown off.

a. Fission hypothesis—Earth spinning too fast leading to some material thrown into space (the Moon).

b. Giant impact hypothesis—late in its history the Earth was hit by a large object throwing material into space (eventually to become the Moon).

Predictions:

1. Binary planet hypothesis:

If the Earth and Moon formed together from the same cloud of dust and gas in a similar way, what composition would we expect for the Moon?

2. Capture hypothesis:

If formed further from the sun than the Earth:

If formed closer to the sun:

3a. Fission hypothesis:

Problem: Even if we recombine the Earth and Moon, the Earth should not have been spinning fast enough to break up.

Thus, the initial fission hypothesis had fallen into disfavor in favor of a modified version:

3b. Giant impact hypothesis:

Testing the predictions

The models all make different predictions.

How might we check the predictions?

Alas, before Apollo we could not obtain the necessary data to distinguish between the models.

An answer had to wait until the analysis of the material and observations made during the Apollo missions in the 1970s.

By the mid-1980s a coherent picture had started to emerge:

What did Apollo find?

Evidence supports which hypothesis?

How likely is such a giant impact?

Idea of giant impact meshes well with evidence for early heavy bombardment.

Modelling suggests that large bodies might be available at the end of planetary formation.

The planet Uranus.

So, we now know that the Moon was formed following a giant impact with the Earth, right?

The testing continues...

As computers have improved researchers have run computer simulations of the impact hypothesis.

Input the physical laws, mass and velocities of the bodies and see what happens.

Suggest that the impact hypothesis is feasible.

Current models suggest Moon should form in low Earth orbit.

Should form very quickly (~100 years).

==> Moon should initially be very hot.

The Scientific Method in Action:

Plate Tectonics

The basic idea behind the theory:

The theory states that rigid lithospheric plates move with respect to each other on the surface of the planet.

How might plates move with respect to each other?

Early evidence for continental drift:

The idea that the continents move is not new.

In 1620, shortly after explorers first created maps of the new world, Francis Bacon noticed how nicely South America and Africa fit together.

In 1858 Antonio Snider showed how these and other continents fit together like a jigsaw puzzle.

Perhaps the continents were once together and drifted apart?

The Ideas of Alfred Wegener

In the early 20th century Alfred Wegener took these earlier ideas and made a case that the continents indeed move.

He gathered evidence from a variety of areas:

1. He showed how the continents could be put together to form one massive continent: *Pangaea*.

2. *Common Fossils*

He showed that several fossils from the paleozoic age found on separate continents are quite similar.

e.g. South America, Africa, India, and Australia

Indeed, in Wegener's reconstruction, these continents fit close together.

3. Common Rock Formations

In addition to fossils, similar rock formations are found in India, Africa, South America, Australia, and Antarctica.

Also North America and Europe.

Again, these continents are close together in Wegener's reconstruction.

4. Paleoclimates

Glacial features appear on the southern continents: South America, Africa, India, and Australia.

India?!?

If India hasn't moved what would a glaciated India suggest about the Earth's climate at this time?

Yet no such evidence on the northern continents.

Indeed, evidence suggests these continents were quite warm at this time:

Coal is created in tropical swamps.

Coal in Norway?

Despite this evidence, many geologists remained unconvinced.

Why?

Why did Geologists Resist Wegener's Ideas?

1. No one could explain what forced the continents to move:

Wegener's original thought was that the continents somehow plow through the oceanic crust.

Did not seem plausible given what was known about the strength of rocks.

2. Geography:

Much of Wegener's evidence came from the southern hemisphere.

Most northern geologists had not seen this evidence firsthand.

Not surprisingly, southern hemisphere geologists were more impressed with the idea of continental drift.

Thus, the idea of continental drift (and plate tectonics) languished for half a century.

The Revival of Continental Drift

During the 1940s and '50s evidence continued to trickle in.

In particular, evidence along two lines proved important in the revival of continental drift:

1. Investigations of the sea floor
2. Geophysical observations, particularly of rock magnetism

Evidence from Paleomagnetism

The Earth generates a magnetic field.

The poles of the magnetic field are near the geographic poles of rotation.

(This is why compasses work—they point towards the magnetic pole which, for most purposes is close enough to the rotation poles).

While the generation of the magnetic field is not fully understood, it is thought to be related to the Earth's rotation.

Thus, it is likely that the two have always been close.

Interestingly, however, the magnetic poles appear to reverse periodically.

Certain minerals (e.g. magnetite) can act like little bar magnets.

==> Rocks containing these minerals are magnetic as well.

These rocks contain records of the past magnetic field of the Earth.

How?

If one heats up a magnet to a certain temperature (the Curie temperature) it loses its magnetism.

If one then cools a magnet (or magnetic rock) below this temperature it will become magnetized along whatever magnetic field is present.

Thus, when a rock is formed from molten magma it will record the strength and direction of the Earth's magnetic field at the time of its formation.

Once solidified this magnetic signature is frozen into the rock.

This signature can be used to determine where the magnetic pole was when the rock was formed.

The magnetic crystals will point towards the pole.

==> direction of the pole. What about distance?

The distance from the pole is determined by the dip of the crystals.

How will they dip near the equator?

In the northern hemisphere?

In the southern hemisphere?

Polar Wander

Magnetic rocks within continents indicate that the pole has changed position in time.

This suggests one of two possibilities:

Either the pole has moved in time

or,

the continent has moved in time.

However, rocks from different continents suggest different positions for the pole at the same time:

Study of the Sea Floor

What about the problem of how continents move?

Studies of the sea floor led to a modification of Wegener's original hypothesis in this regard.

The discovery of the mid-oceanic ridge led Harry Hess in 1962 to suggest that it was the sea-floor, not the continents, which moved.

This proposal became known as sea-floor spreading because he proposed that the sea floor spread away from the mid-oceanic ridge.

He proposed mantle convection as the driving force.

Sea-floor spreading provided a plausible mechanism for the motion of the continents.

Nice theory. Is there any evidence for this?

Wegener's continental drift and sea-floor spreading have been combined into the theory of Plate Tectonics.

Theory of plate tectonics has revolutionized geology.

Prior to plate tectonics people tended to look for local explanations for geologic features.

Plate tectonics has provided a global, unifying, theme to geology.

Plate tectonics helps explain many of the geologic features and processes we see on Earth:

Location of earthquakes.

Location and types of volcanism.

Mountain building.

Metamorphism.