Astronomy 101
The Solar System
Tuesday, Wednesday, Thursday

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Shaping Planetary Surfaces

- Impact Cratering
- Volcanism
- Tectonics
- Erosion
Cratering

Meteor Crater, Arizona

http://www.solarviews.com/eng/tercrate.htm
Galle Crater, Mars
Callisto (Moon of Jupiter)

http://ase.tufts.edu/cosmos/view_picture.asp?id=726
Volcanism
Erosion

- Processes that break down or transport rock through the action of ice, liquid, or gas
- Movement of glaciers
- Formation of canyons by running water
- Shifting of sand dunes by wind
Energy of Impact (K-T)

- \( v = 17 \text{ km/s} \)
- Density = 3,000 kg/m\(^3\)
- Diameter = 2*radius = 10 km
- Volume = \( \frac{4}{3}\pi r^3 = 5.23 \times 10^{11} \text{ m}^3 \)
- Mass = density*volume
- Mass = 1.57 \times 10^{15} \text{ kg}
- Kinetic energy = \( \frac{1}{2} mv^2 \)
- Kinetic energy = 2.27 \times 10^{23} \text{ Joules}
- Kinetic Energy = 5.42 \times 10^7 \text{ Megatons of TNT}
- Largest Nuclear Bomb is 100 Megatons of TNT
Gene Shoemaker

Parts taken from talk of Bridget Mahoney
• Shoemaker wrote his Ph.D thesis on Meteor Crater
• Shoemaker did seminal research in the mechanics of meteorite impacts
In 1952, Shoemaker hypothesized that Meteor Crater as well as lunar craters were created by asteroidal impacts. USGS sent Shoemaker to the Yucca flats to investigate small nuclear events to compare with Meteor Crater,
Quartz ($\text{SiO}_2$)
Coesite

- While doing research in the Yucca flats on meteorite impact with David Chao, the pair discovered Coesite.
- **Coesite** ($\text{SiO}_2$) is a mineral that is produced during violent impact.
- Different crystal structure than quartz.
Chixculub Crater

Taken from presentation by Amanda Baker
K-T Boundary

- 65 million years ago
- Boundary in the rock record separating the Cretaceous and Tertiary Periods
- Corresponds to one of the greatest mass extinctions in history
- Global layer of clay separating the two periods
- First proposed by Walter Alvarez
We know it happened but where?

- A Circular geophysical anomaly, now known to define the Chicxulub structure, was originally identified on the northern edge of the Yucatan Peninsula during oil surveys in the 1950's.
Chixculub

- Translates to “tail of the devil” in Mayan
- The meteorite's estimated size was about 10 km (6 mi) in diameter, releasing an estimated $4.3 \times 10^{23}$ joules of energy (equivalent to 191,793 gigatons of TNT) on impact.
Data

- Seismic, gravity and magnetic data define a structure ~180 km in diameter.
What happened?

• An asteroid roughly 10 km (6 miles) across hit Earth about 65 million years ago.

• This impact made a huge explosion and a crater about 180 km (roughly 110 miles) across.

• Debris from the explosion was thrown into the atmosphere, severely altering the climate, and leading to the extinction of roughly 60% of species that existed at that time, including the dinosaurs.
Environmental Damage

• The worst hit organisms were those in the oceans.
• On land, the Dinosauria of course went extinct, along with the Pterosauria.
• Mammals and most non-dinosaurian reptiles seemed to be relatively unaffected.
• The terrestrial plants suffered to a large extent, except for the ferns, which show an apparently dramatic increase in diversity at the K-T boundary, a phenomenon known as the fern spike.
• Pterosaurs were flying reptiles
Dinosaurs lived during the Mesozoic Era, from late in the Triassic period (about 225 million years ago) until the end of the Cretaceous (about 65 million years ago).
• Modern birds are considered to be the direct descendants of dinosaurs
Tunguska

- Occurred in 1908
- Huge explosion in the atmosphere
- Thought to be asteroid or comet that exploded in mid-air 6 to 10 kilometers above the Earth's surface
- Energy of 10 and 15 megatons of TNT
- Equivalent to the most powerful nuclear bomb detonated in the USA
- There wasn’t a large expedition to the site until 1927
Evidence for extraterrestrial impact

- No large meteorite fragments were found
- Found were microscopic glass spheres that contained high proportions of nickel and iridium
Other ideas

• http://en.wikipedia.org/wiki/Tunguska_event
Craters

• Tend to be round unless it is an oblique impact

Tycho crater on Moon

Diameter 85 km
Depth 4.8 km

Moon
(180 x 65 km).

http://www.boulder.swri.edu/~bottke/Oblique_craters/oblique.html

Mars
(380 x 140 km)

http://www.boulder.swri.edu/~bottke/Oblique_craters/oblique.html
Craters

Simple Crater

Breccia
Impact melt
Impact ejecta
Fractured bedrock
Central peak uplift

Complex Crater
• Complex craters tend to be larger than simple craters
• Complex Craters
  – gravity causes the steep crater walls to collapse, which makes complex craters very shallow
  – Central uplift where the earth rebounds from the impact
Complex

Peak Ring
Central peak Collapses

(Melosh, 1989)
Different types of craters

- http://www.classzone.com/books/earth_science/terc/content/investigations/es2506/es2506page07.cfm
• Small craters are usually much more common than larger ones

• More craters at smaller sizes - older
Dating through crater counting
(Things to bear in mind)

- Impact rate and size distribution of impacting bodies
- Temporal and spatial variations in impactor population
- Temporal variation in the target
- Crater degradation
- Secondary impacts
- Need for measured surface ages to calibrate counting
Calibration

- Moon – we have samples from specific places
- Other planets – no samples
• Cratering rate will be different on Mars compared to the Moon
  – Mars has larger mass so larger flux (gravitational focusing)
  – Mars closer to asteroid belt (more possible impactors)
• The Moon's orbital period is 27.322 days
• Rotation period and orbital period are the same
• This means we keep on seeing the same side of the Moon
Moon

• The Moon is the only known natural satellite of Earth.

• Compared with the satellites of other planets of the solar system, The Moon is a large moon with a diameter of 3476 km and a mass of $7.349 \times 10^{22}$ kg.

• The Moon is an average distance of 384,400 km from Earth and completes its revolution of Earth in 27.32 days.
• The Earth's magnetic field strength is about 100 times higher than the highest value measured on the Moon by the Apollo missions.

• The Moon does not have a magnetic field like the Earth (North and South Poles) due most likely to having a solid (or only partially molten) core.

• Earth’s core is convecting.

• A flowing molten iron-nickel material can produce electrical current, which, in turn produces a magnetic field that surrounds the Earth.

• The first manmade object to land on the Moon was Luna 2 in 1959
• The first photographs of the far side of the Moon were made by Luna 3 that same year
Who proposed an American mission to the Moon in 1962?
Houston, Texas  
September 12, 1962

• We choose to go to the Moon. We choose to go to the moon in this decade and do the other things, not only because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too.
The first people to land on the Moon came aboard Apollo 11 in 1969.
Regolith – Lunar soil
No moisture or organic component compared to terrestrial soil
Who was the 1st person to walk on the Moon
Who was the 1\textsuperscript{st} person to walk on the Moon

- Neil Armstrong
- Apollo 11
Who was the 2nd person to walk on the Moon
Who was the 2nd person to walk on the Moon

- Buzz Aldrin
- Apollo 11
Moon

- 30,000 craters having a diameter of at least 1 kilometer
- Large craters are named after famous deceased scientists, scholars, and artists
• The largest crater on the Moon, and indeed the largest known crater within the solar system, forms the South Pole-Aitken basin.
• Roughly 2,500 kilometers in diameter and 13 kilometers deep
South Pole-Aitken Basin
Orthographic Projections centered at -56, 180

Albedo

Topography

Iron

Titanium
Central part of South Pole-Aitken Basin

http://www.nhk.or.jp/kaguya/archive/index_e.html
The dark and relatively featureless lunar plains are called maria, Latin for seas, since they were believed by ancient astronomers to be water-filled seas.

They are actually vast ancient basaltic lava flows that filled the basins of large impact craters.

Maria are found almost exclusively on the Lunar nearside, with the Lunar farside having only a few scattered patches.
Far Side of Moon
Other features on Moon

- **Rille** - long, narrow depressions in the lunar surface that resemble channels.
- **Floor of Gassendi crater**
- **Leading theories for rille formation** include collapsed lava tubes and tectonic extension.

Other features on Moon

- Scarp – steep slope or cliff
- The Altai Scarp, which is the rim of the 860 km wide Nectaris impact basin, is nearly 500 km long and 3 to 4 km high.

http://www.lpod.org/?m=20060517
Stratigraphy

- Stratigraphy – studies rock layers and layering
- On planetary bodies, we try to determine the relative ages when things formed
Principle of Superposition

[Image showing a diagram of stratigraphy with labeled layers and indications of youngest and oldest layers.]

http://earthsci.org/fossils/geotime/time/Super.gif
Principles of cross-cutting relationships

http://dept.kent.edu/geology/ehlab/fundamentals/cross_cut.gif
Crater Rays

- Historically, they were once regarded as salt deposits from evaporated water (early 1900s) and volcanic ash or dust streaks (late 1940s).
- Now rays are recognized as fragmental material ejected from primary and secondary craters during impact events.
Crater Rays

- In laboratory sand-layer vertical impacts, the ejecta does come out evenly around the crater.
- But in a real impact, there are a number of complicating factors.
- There can be variations in the strength (from pre-existing fractures in the surface, or inhomogeneties in the target rock) that lead to "jetting" of ejecta and presumably the rays.

Copernicus
93 km wide

Tycho
85 km wide

http://apod.nasa.gov/apod/image/0503/moon8_mandel.jpg
• Only 2.5% of the surface of the far side is covered by mare, compared to 31.2% on the near side.
• The likely explanation is that the far side crust is thicker, making it harder for molten material from the interior to flow to the surface and form the smooth maria.
Why do we always see the same side of the Moon?

• Tidal locking of the Moon's rotation to its orbit (the phenomenon whereby the Moon spins on its axis in the same timespan as it takes to orbit the Earth).
• The lighter-colored areas are called the highlands
• **Luna 2** - impact on the surface of the Moon (1959) (USSR)
• **Luna 3** - first photos of the far side of the Moon (1959) (USSR)
• **Apollo** - Six manned landings on the Moon with sample return 1969-72.
  - (The seventh landing, Apollo 18, was canceled for political reasons)
• **Luna 16** - automated sample return from the Moon (1970) (USSR)
• **Clementine** - a joint mission of the Ballistic Missile Defense Organization and NASA (1994)
• **Lunar Prospector** - the first NASA mission to the Moon in almost 30 years (1998-1999)
• **SMART-1** - The European Space Agency’s (ESA) spacecraft orbited the Moon and then crashed into the Moon in (September, 2006)
Currently

- Japanese SELENE mission (also known as Kaguya) orbited the Moon from 2007-2009
- Goal was "to obtain scientific data of the lunar origin and evolution and to develop the technology for the future lunar exploration"

http://www.selene.jaxa.jp/en/about/image/img_equipment_001_e.jpg
Pythagoras Crater from SMART-1

http://www.space.com/imageoftheday/image_of_day_060626.html
http://cdn2.libsyn.com/astronomy/moon_show20.gif?nvb=20081110153501&nva=20081111153501&t=0b619a8f8100c5f7820f5
Pythagoras Crater from Selene

Diameter 130 km, Depth 5.0 km

• http://space.jaxa.jp/movie/20080411_kaguya_movie01_e.html
Currently

• India's national space agency launched Chandrayaan-1, an unmanned lunar orbiter, on October 22, 2008.
• Estimated cost was $80 million
• Its scientific objectives was to prepare a three-dimensional atlas of the near and far side of the moon and to conduct a chemical and mineralogical mapping of the lunar surface.
• Mission ended on August 29, 2009
Chandrayaan-1

Water on Moon

![Graph showing apparent reflectance vs wavelength for different regions on the Moon.](graph.png)
How much water?

• The Moon’s surface holds as much as a liter of water in every metric ton (1,000 kg) of lunar soil
A total of 382 kg of rock samples were returned to the Earth by the Apollo and Luna programs.

- Apollo - 381.69 kg
- Luna – 300 g
Apollo 15 sample
“Genesis Rock”
Very ancient sample
4 billion years old

Did We Land on the Moon

- http://www.youtube.com/watch?v=LHzuflymeEE&feature=related
Rocks and More Moon
• **Mineral** – A naturally occurring, homogeneous inorganic solid substance having a definite chemical composition and characteristic crystal structure

• **Rock** - naturally occurring aggregate of minerals
Forming Different Mineralogies

- Can be on a planet-scale
- Or a few meters to kilometers
Some minerals form before other minerals.
What minerals form?

- Depends on the composition of the magma
- Depends how quickly the magma cools
Types of Rocks

- **Igneous** – rock that solidified from molten or partially molten material
- **Metamorphic** - rock that has changed in composition, mineral content, texture, or structure by the application of heat or pressure
- **Sedimentary** – rock formed from material that was deposited as sediment by water, wind, or ice and then compressed and cemented
Igneous Rock

Metamorphism

Sedimentary

- Examples of two types of sedimentary rock: limey shale overlaid by limestone

• Rock formed from sediments covers 75-80% of the Earth's land area
Lunar Meteorites

• 44 known as of today
• only 1 in 1200 meteorites are lunar
• Lunar meteorites go for $800 and $40,000 per gram. By comparison, the price of 24-carat gold is about $20 per gram and gem-quality diamonds start at $1000-2000/gram.

http://epsc.wustl.edu/admin/resources/moon_meteorites.html
• Highlands – contain Al-rich material
  – Plagioclase feldspar - CaAl$_2$Si$_2$O$_8$
• Mare – contain Fe-rich material – basaltic eruptions
  – Olivine - (Mg, Fe)$_2$SiO$_4$
  – Pyroxene – (Mg,Fe)SiO$_3$
  – Ilmenite - FeTiO$_3$
Magma Ocean

Anorthosite crust formation

- Completely molten magma
- Not molten

Magma

- Feldspar
- Olivine
- Pyroxene
How do you form the Moon?
Definitions

- Volatile – evaporates easily
- Refractory – does not evaporate easily
Need to account for these things

- The Moon's low density (3.3 g/cc) shows that it does not have a substantial iron core like the Earth does.
- Moon rocks contain few volatile substances (e.g. water), which implies extra baking of the lunar surface relative to that of Earth.
- The relative abundance of oxygen isotopes on Earth and on the Moon are identical, which suggests that the Earth and Moon formed at the same distance from the Sun.
Oxygen Isotopes

- There are three stable isotopes of oxygen.
- They have masses of 16, 17, and 18 atomic mass units.

\[
\begin{align*}
1^6\text{O} & \approx 99.762 \\
1^7\text{O} & \approx 0.038 \\
1^8\text{O} & \approx 0.200
\end{align*}
\]

- The oxygen isotopic ratios (\(1^7\text{O}/1^6\text{O}\) and \(1^8\text{O}/1^6\text{O}\) of silicate rocks from the Earth and Moon are the same and are different from most meteorites and Mars.
Atmosphere

• Not much of an atmosphere since the Moon’s gravity is so small
Any Questions?