“The Planets”

Astro/EPS C12 (CCN 17045 or 32505)

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LEC: 2 LeConte TWTh, 2:40–5:00pm
Office Hours: 419 Campbell Hall, Mon 3–4 and Tue 5–6

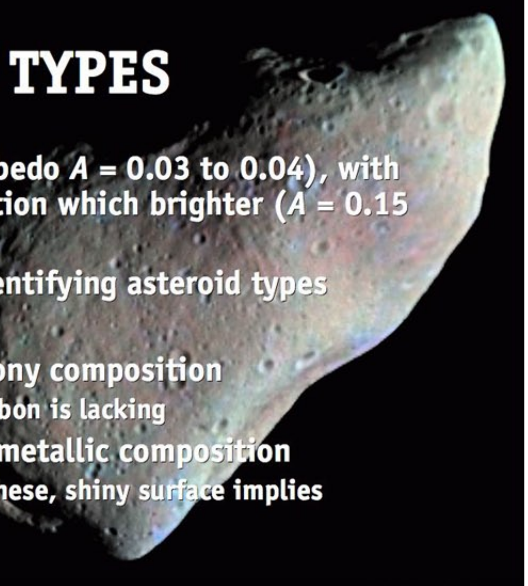
GRADES

- grading option change deadline 1 August

MIDTERM grade	cutoff	N
A	45.00	17
B	40.00	16
C	35.00	16
D	30.00	9
F	0.00	7
		65

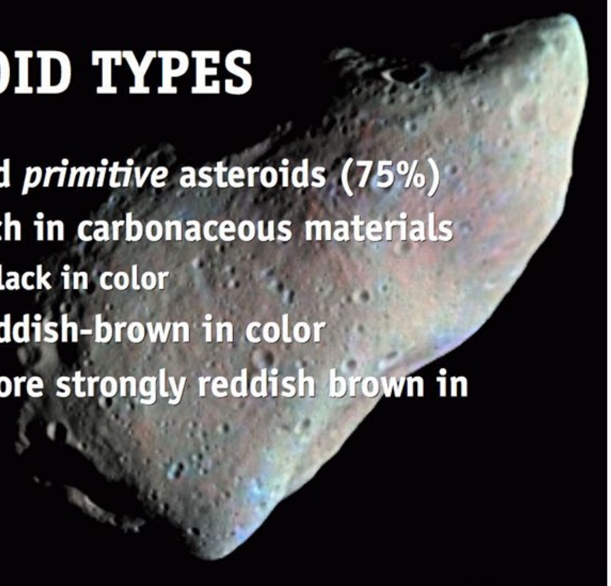
TOTAL grade	cutoff	N
A	72.00	14
B	62.10	13
C	54.60	13
D	48.00	14
F	0.00	11

ASTEROID TYPES



- Most are dark (albedo A = 0.03 to 0.04), with a significant fraction which brighter (A = 0.15 to 0.20)
- Spectra key in identifying asteroid types
- S-type (17%): stony composition
  - Brighter since carbon is lacking
- M-type (few %): metallic composition
  - Hard to confirm these, shiny surface implies metallic surface

ASTEROID TYPES

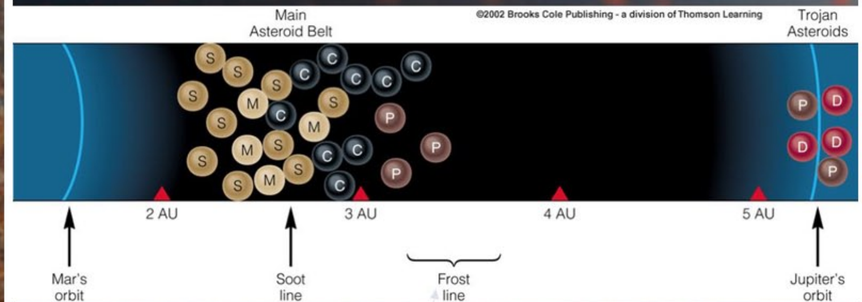


The dark and *primitive* asteroids (75%)

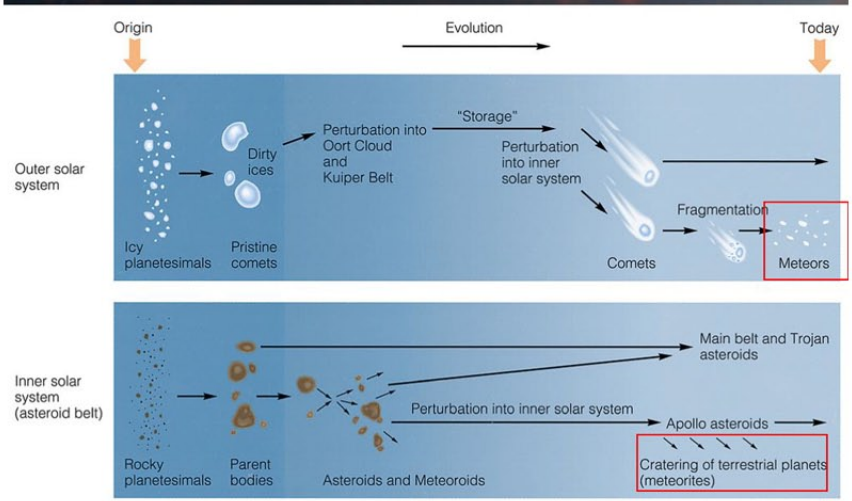
- C-type: rich in carbonaceous materials
  - neutral black in color
- P-type: reddish-brown in color
- D-type: more strongly reddish brown in color

CHONDRITES

- meteorites from primitive asteroids are called chondrites...
- because many of them have chondrules, very old chunks of formerly molten material



Frozen water is stable



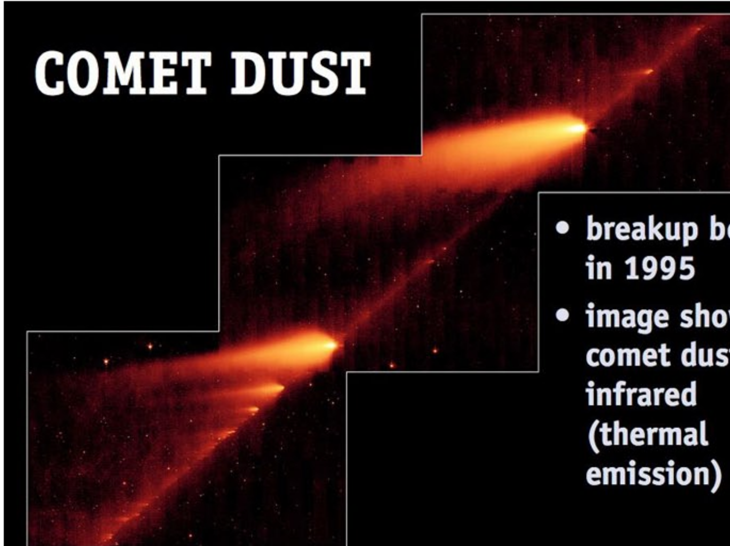
MARTIAN METEORITES ON EARTH

METEORITES

- meteoroid -- a rock or dust grain in space
- meteor -- object entering the atmosphere
- meteorite -- surviving debris that reaches the ground

(micrometeorites are very small versions)

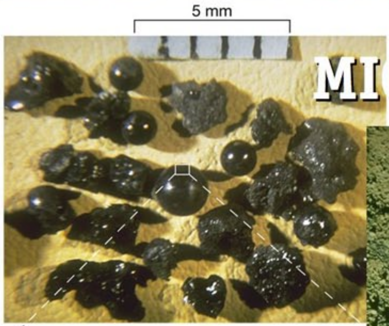
COMET DUST

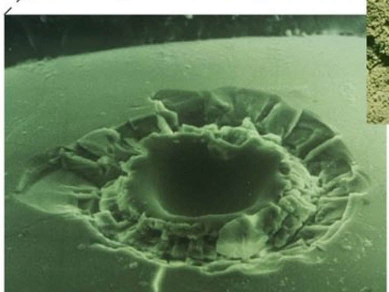


- breakup began in 1995
- image shows comet dust in infrared (thermal emission)

Comet 73P/Schwassmann-Wachmann 3 Spitzer Space Telescope • MIPS
NASA / JPL-Caltech / W. Reach (SSC/Caltech) ssc2006-13a

MICROMETEORITES

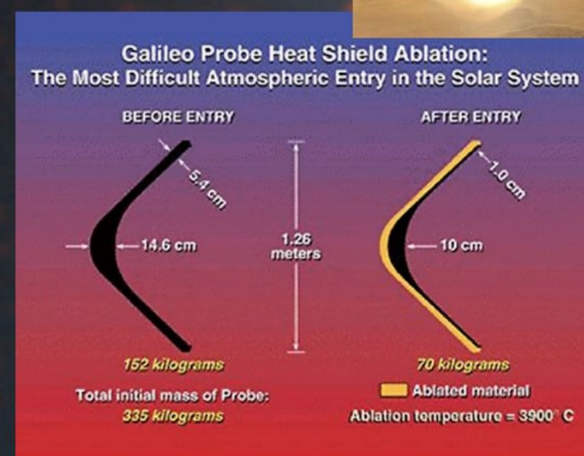




over time, micrometeorite impacts produce a dusty soil called the REGOLITH

ABLATION

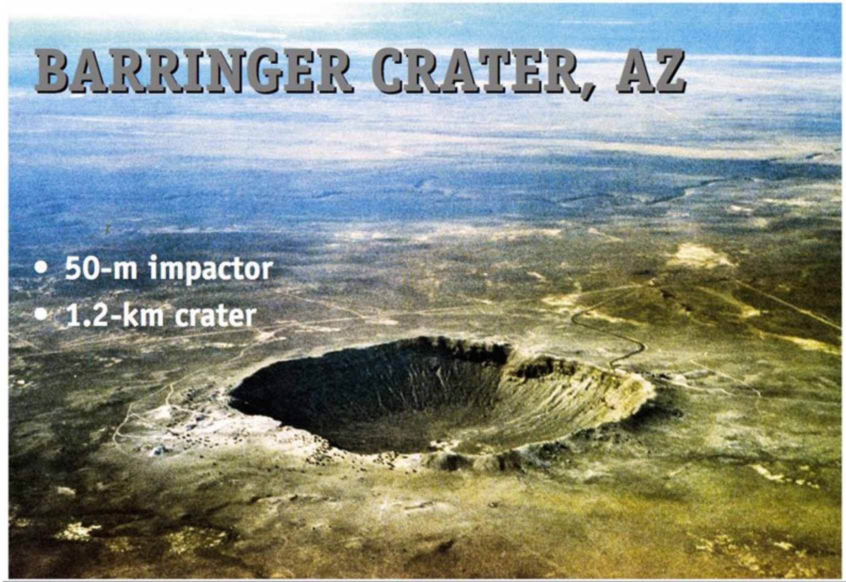
- heated material falls off the impactor
- concept used in heat shields for atmospheric entry probes



ACCEPTANCE OF IMPACT CRATERING

- craters on Earth/Moon originally thought to be volcanic
- work in 1950s/60s (including work by Gene Shoemaker) changed this thinking
- example: Meteor (Barringer) Crater
  - iron meteorite fragments found nearby
  - ejecta stratigraphy is different (ejecta flap)
  - "shocked" rocks found below crater

BARRINGER CRATER, AZ

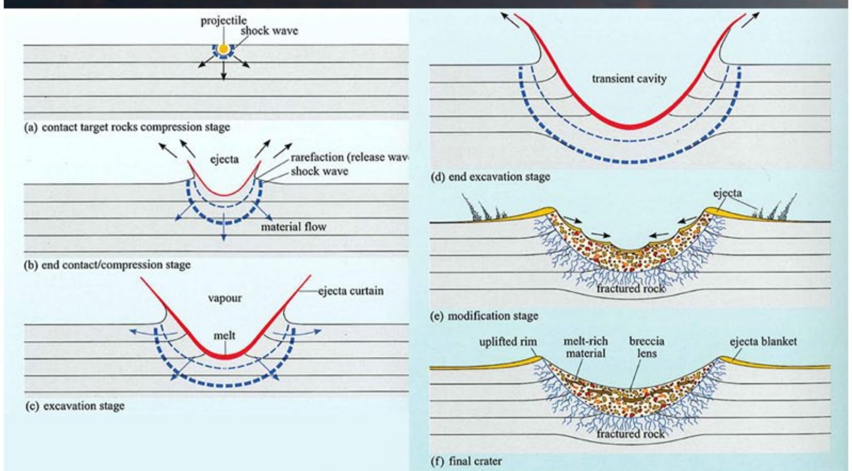


- 50-m impactor
- 1.2-km crater

SIZE OF IMPACTOR

- microscopic dust: floats down through the atmosphere
- 10 m or less: loses mass through ABLATION and slows to FREE-FALL VELOCITY of < 1 km/sec. may form a small crater
- 10 m or more: hypervelocity impact
  - energy release similar to explosion
  - shock compression

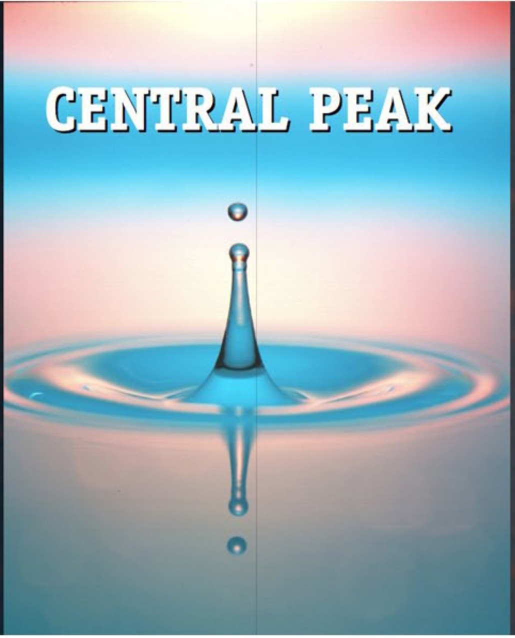
CRATER FORMATION



CRATER TYPES

- depends on impact energy, target gravity, and strength of target material
- simple craters: bowl shaped
  - < 2–4 km on Earth
  - < 10–20 km on Moon
  - < 7 km on Mercury
- complex craters
  - central peak from rebound
  - "terraces" from slumping
- multi-ring basins
  - largest of all
  - asthenospheric motions cause lithospheric fractures

CENTRAL PEAK

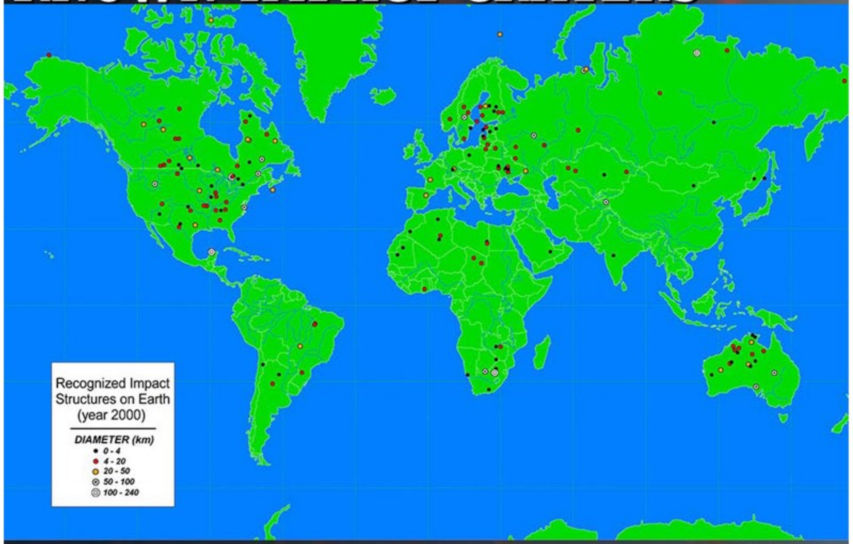


- formed by rebounding material

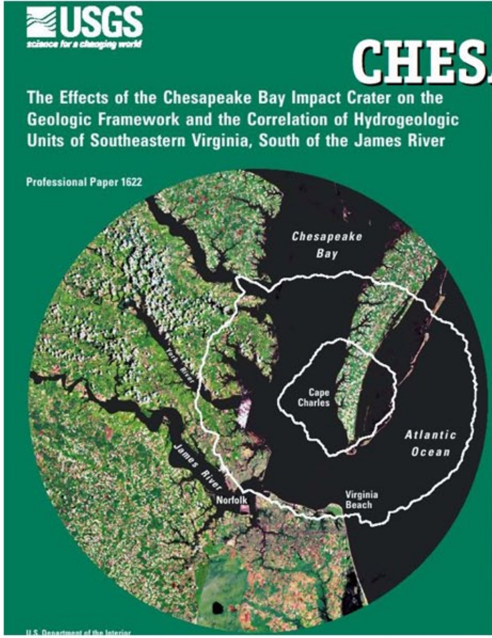
THE WORLD'S LARGEST IMPACT CRATERS - TOP 10

- Vredefort [1], at 300 km in diameter, is the Earth's biggest impact structure. The hole was gouged out two billion years ago
- Chicxulub [3] was made in an event linked to the extinction of the dinosaurs. The impact was dated to 65 million years ago
- Beaverhead [10], 60 km wide, was created 600 million years ago.

KNOWN IMPACT CRATERS



CHESAPEAKE



- 90-km crater
- ~40 million years ago
- EROSION has hidden the crater

MANICOUAGAN RES.

- in Quebec
- 70-km crater
- 200 million years ago

TUNGUSKA

- Siberia, 1908

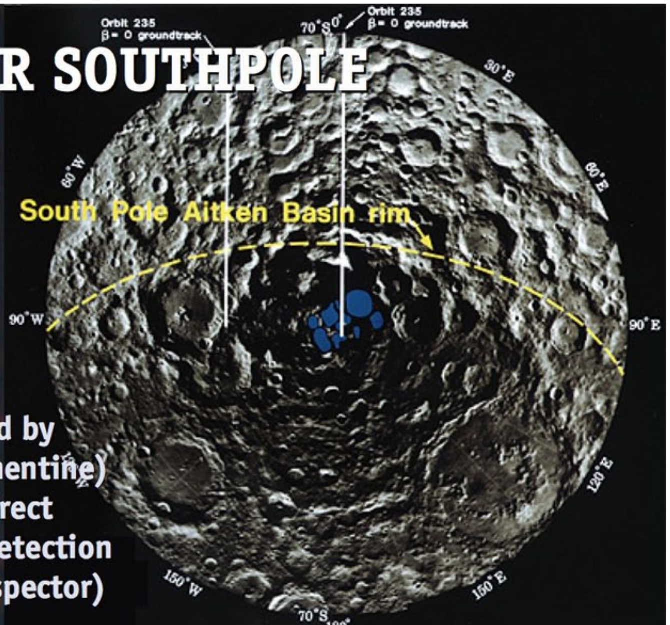
TUNGUSKA t=~5 min.

- 15 km distance

IMPACTS AND ATMOSPHERES

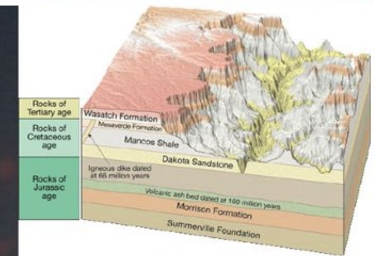
- atmospheres can shield the surface from small impactors
- watery comets may have brought some of the Earth's water to the planet
- very large impacts can remove a big fraction of planetary atmospheres via ATMOSPHERIC EROSION

LUNAR SOUTHPOLE



- ice detected by radar (Clementine) and by indirect hydrogen detection (Lunar Prospector)

IMPACTS and STRATIGRAPHY



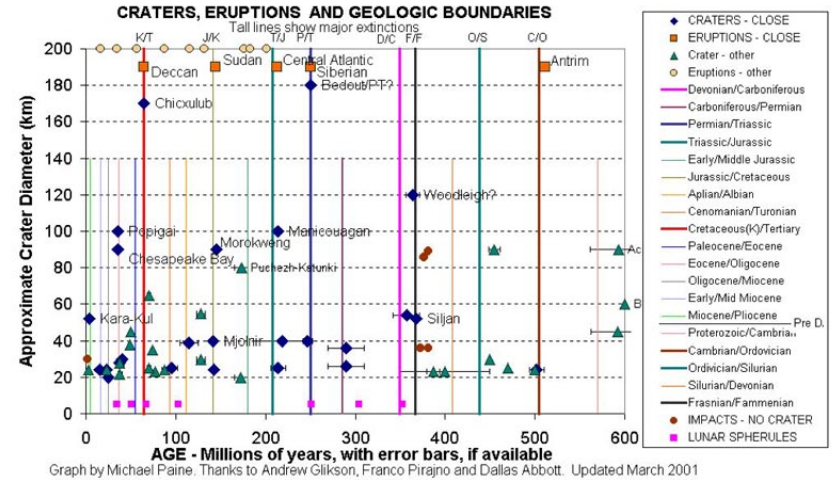
- stratigraphy: the study of chronological rock layers
- older layers are buried under newer layers
- fossils can help with dating
- example: Grand Canyon

- Cretaceous-Tertiary mass extinction was originally linked to an impact by a layer of iridium
- iridium more common in meteorites than in the Earth's crust

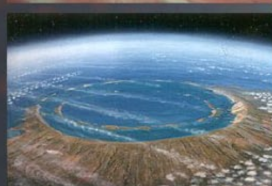
COMPOSITION:EARTH vs MOON

	CI chondrite (primitive meteorite)	Earth (crust + mantle)	Moon (crust + mantle)	Ratio of trace element abundance Moon/Earth
Volatile[a] elements				
K (ppm)	545	180	83	0.46
Rb (ppm)	2.32	0.55	0.28	0.51
Cs (ppb)	279	18	12	0.67
Moderately volatile				
Mn (ppm)	1500	1000	1200	1.20
Refractory elements				
Cr (ppm)	3975	3000	4200	1.40
Th (ppb)	30	80	112	1.40
Eu (ppb)	87	131	210	1.60
La (ppb)	367	551	900	1.63
Sr (ppm)	7.26	17.8	30	1.69
U (ppb)	12	18	33	1.83
Siderophile[b] elements				
Ni (ppm)	16500	2000	400	0.200
Mo (ppb)	1380	59	1.4	0.024
Ir (ppb)	710	3	0.01	0.003
Ge (ppb)	48000	1200	3.5	0.003

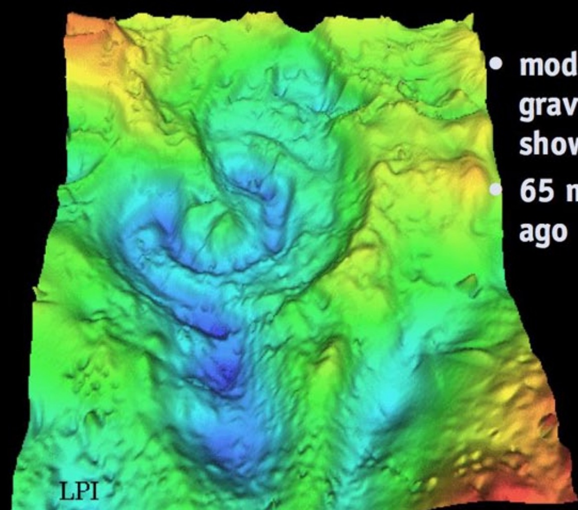
CRATERS AND EXTINCTIONS



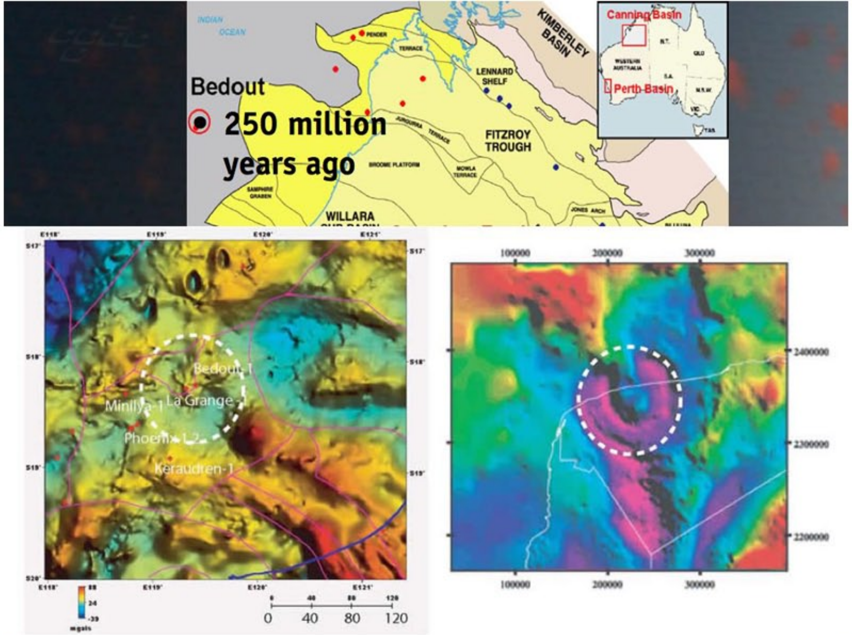
CHICXULUB



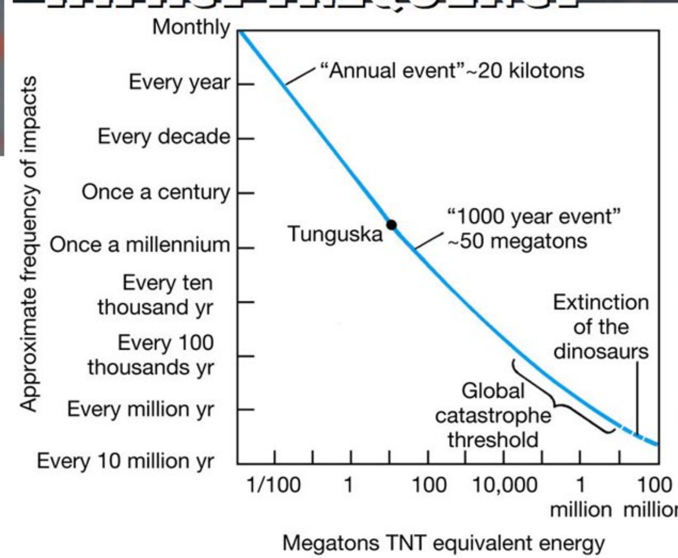
CHICXULUB

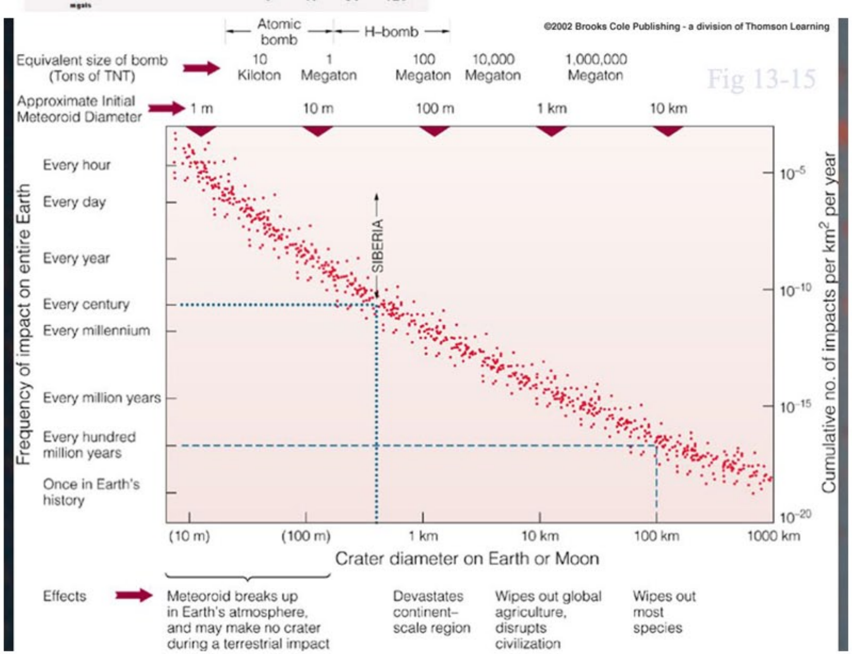


- modeling of gravity data shown
- 65 million years ago



IMPACT FREQUENCY





CRATER DENSITY REVEALS AGE

- more craters means the surface has been around for longer
- crater-free surfaces are the youngest surfaces in the Solar System
- the process of determining the relative ages of surface features is called STRATIGRAPHY

COUNTING CRATERS

- crater densities represented as craters per km^2
- “size-frequency distributions” show the same thing but as a function of crater size
- small craters are more common, large craters are more rare, which tells you about the impactor size distribution
- gravitational focusing, atmospheres, and surface age affect size-frequency distributions

COUNTING CRATERS

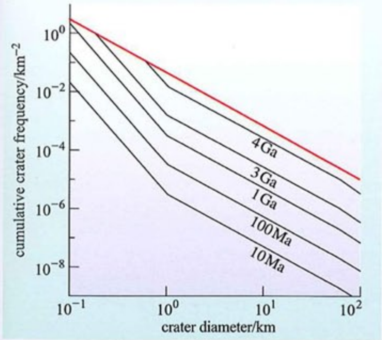


Figure 4.26 ‘Calibrated’ cratering curves for the Moon, based on statistics for surfaces whose ages have been determined radiometrically. The red line shows the crater density on a saturated surface.

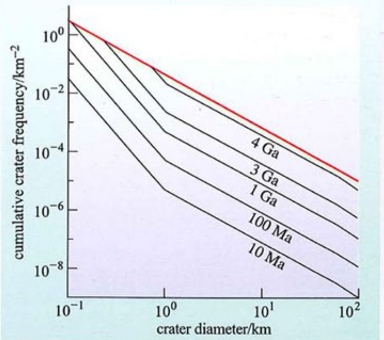
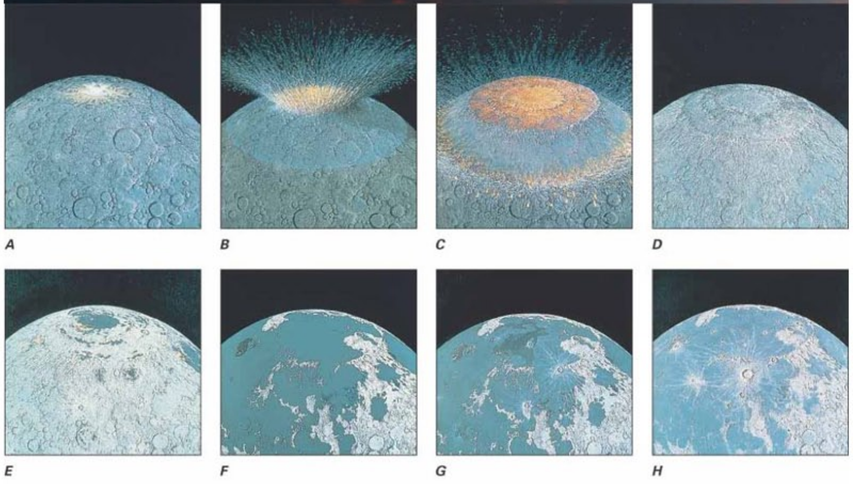


Figure 4.27 Cratering curves for Mars, based on lunar data in Figures 4.25 and 4.26, but adjusted to take account of the slightly higher flux at Mars. Notice it is very similar to Figure 4.26.

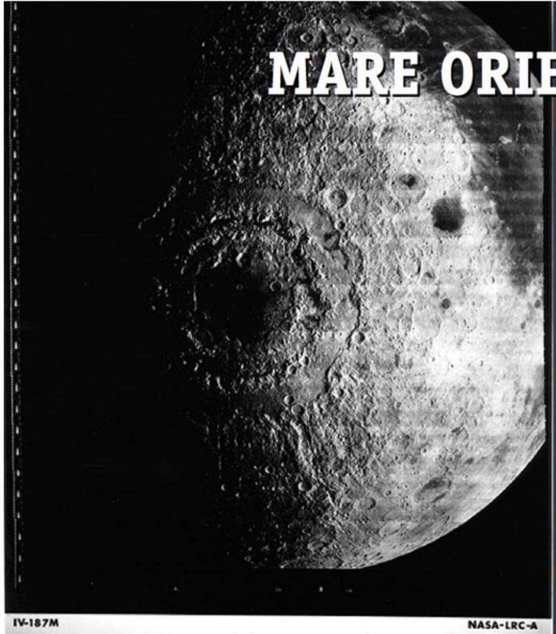
CRATER DENSITY REVEALS AGE

MARE IMBRIUM



MIMAS

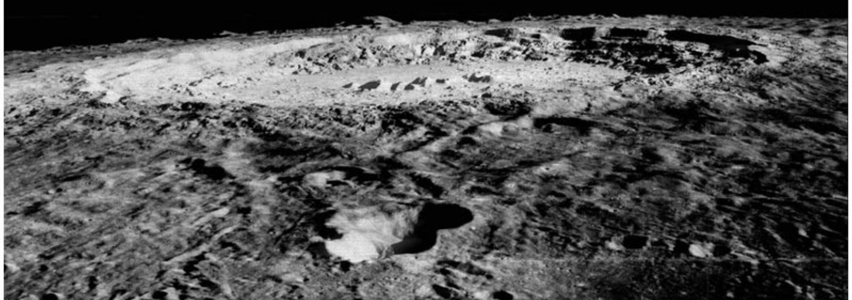
MARE ORIENTALE



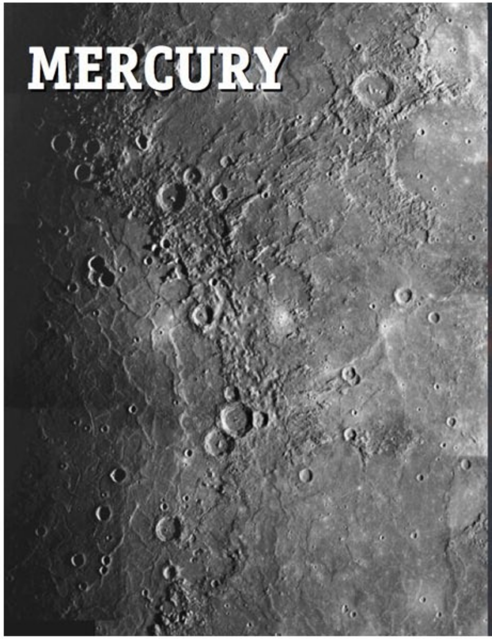
- 1000-km crater

COPERNICUS

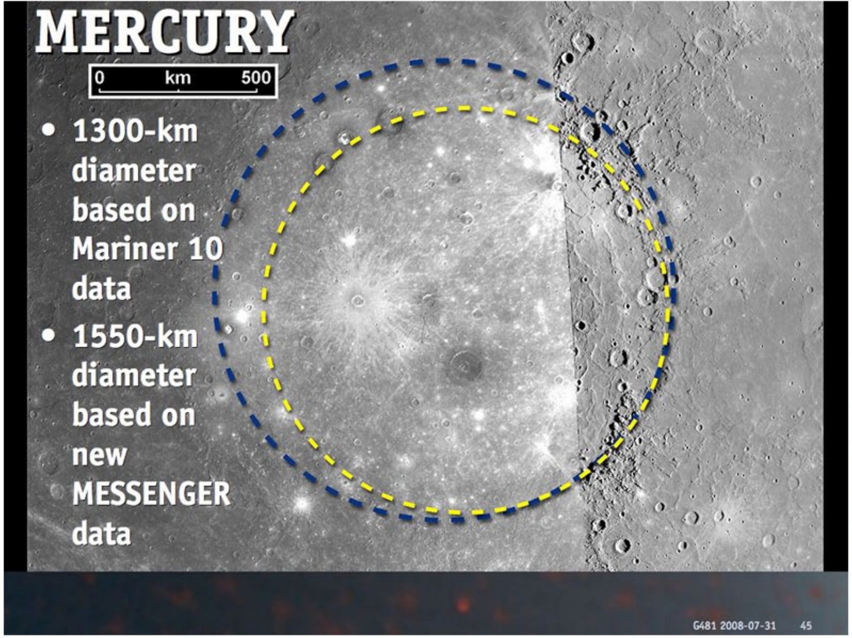
- 93-km crater

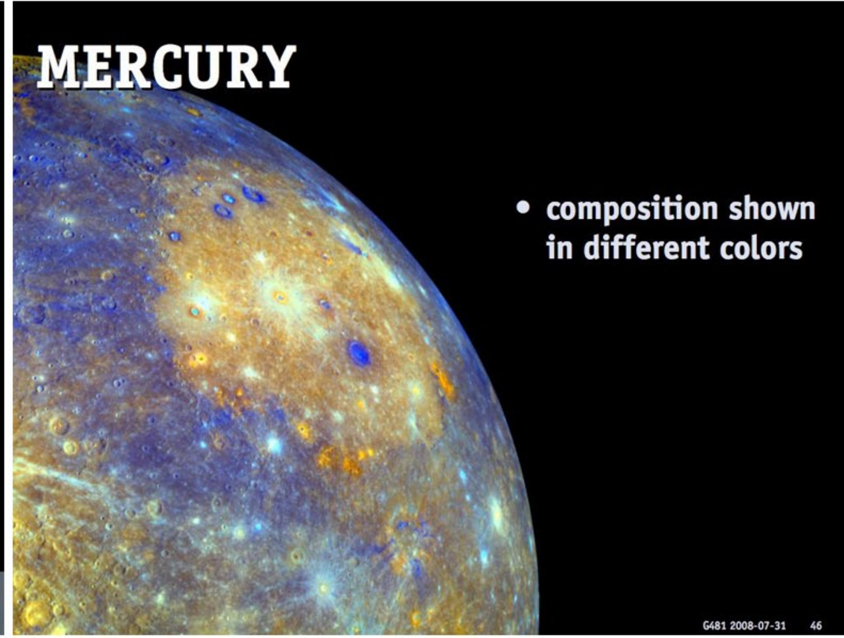


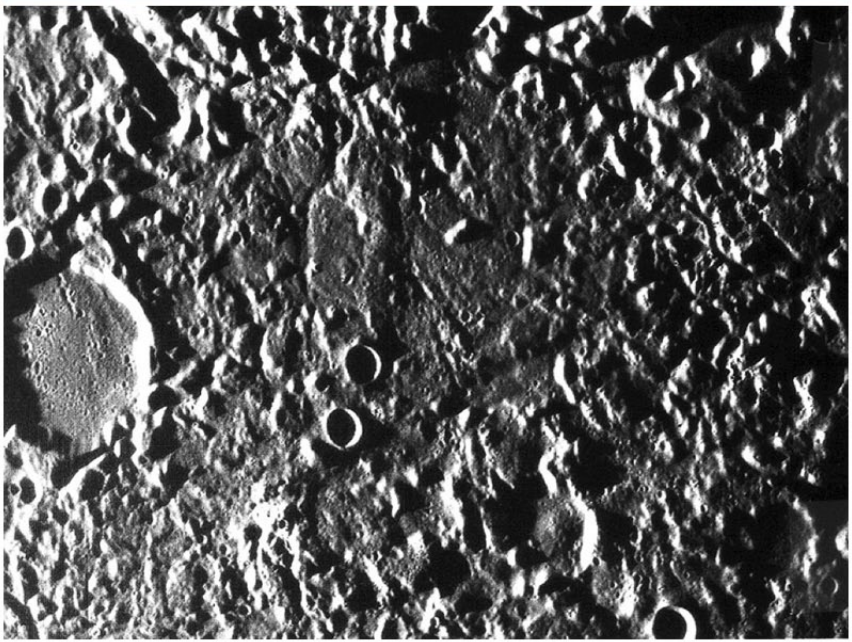
MERCURY

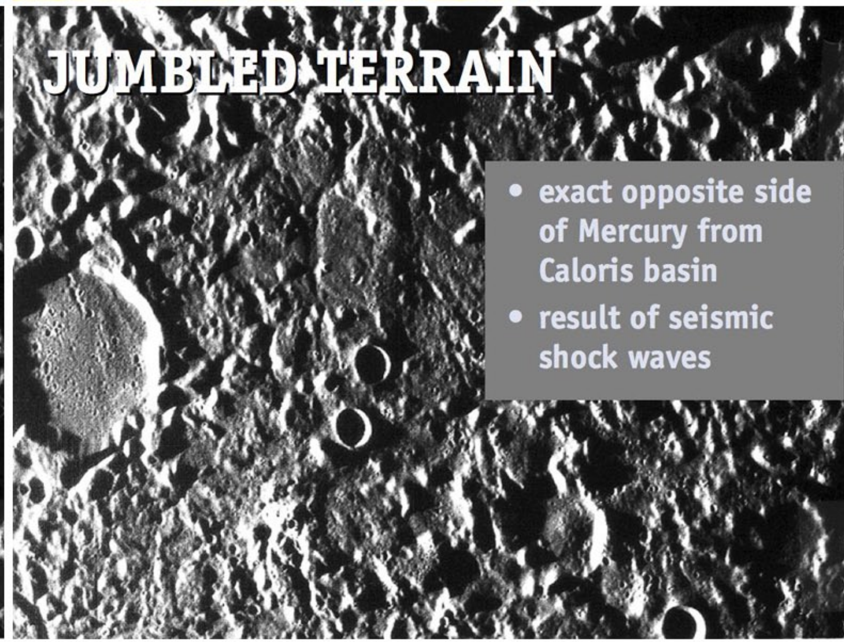


- Caloris basin
- 1400-km crater
- Mariner 10 image (1973)
- Messenger mission will fly by Mercury Jan. 2008 and return to Mercury in 2011

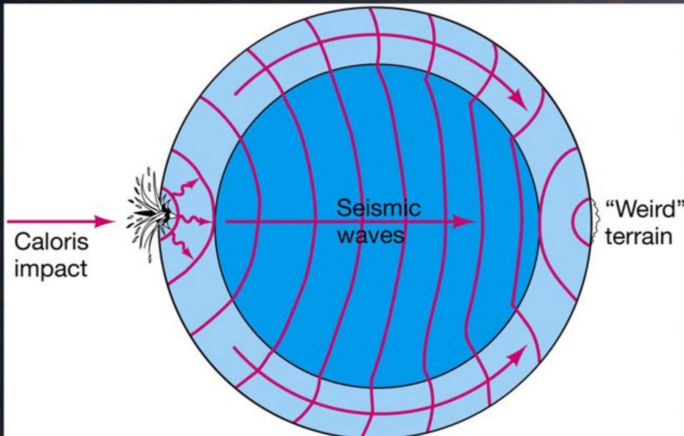

MERCURY
0 km 500
• 1300-km diameter based on Mariner 10 data
• 1550-km diameter based on new MESSENGER data
G481 2008-07-31 45


MERCURY
• composition shown in different colors
G481 2008-07-31 46




JUMBLED TERRAIN
• exact opposite side of Mercury from Caloris basin
• result of seismic shock waves

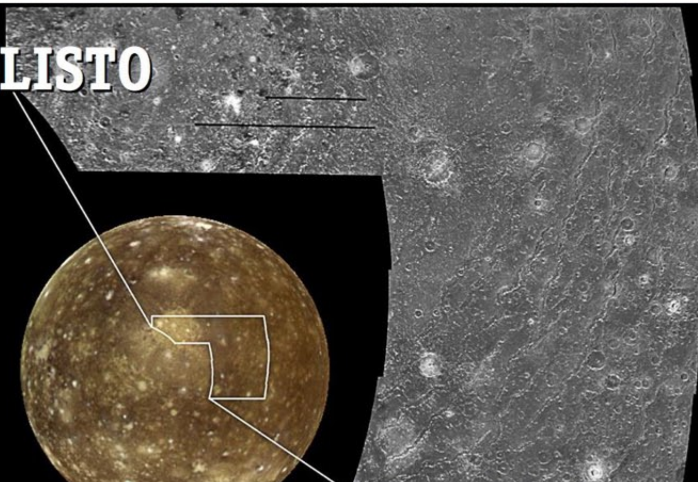
JUMBLED TERRAIN



MERCURY

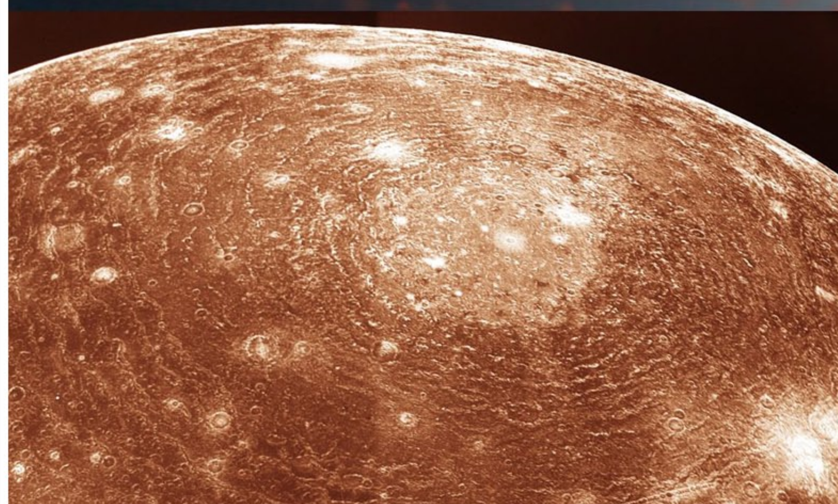
- pair of 40-km craters on Mercury
- rays of cratering ejecta

CALLISTO

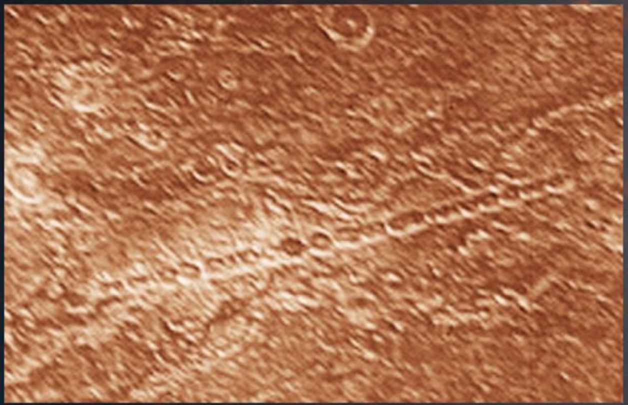


- Valhalla multi-ring basin
- 4000-km diameter crater
- Galileo orbiter image

VALHALLA AGAIN

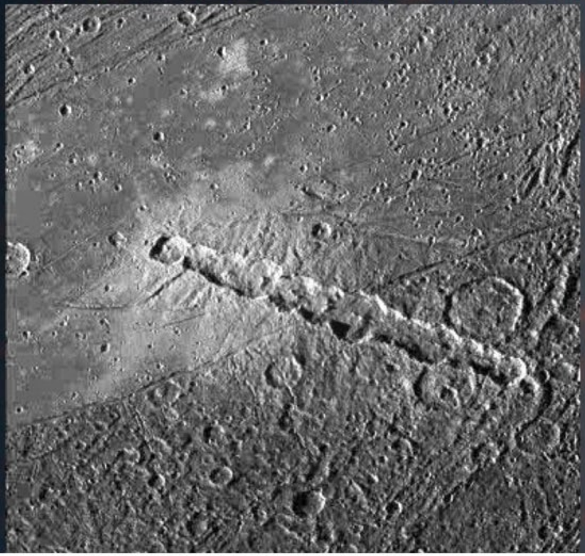


CALLISTO CRATER CHAIN



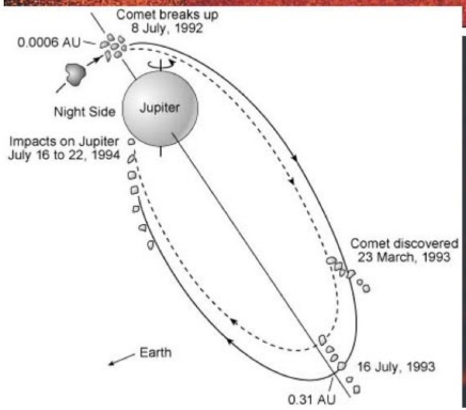
- Galileo orbiter image

GANYMEDE CRATER CHAIN

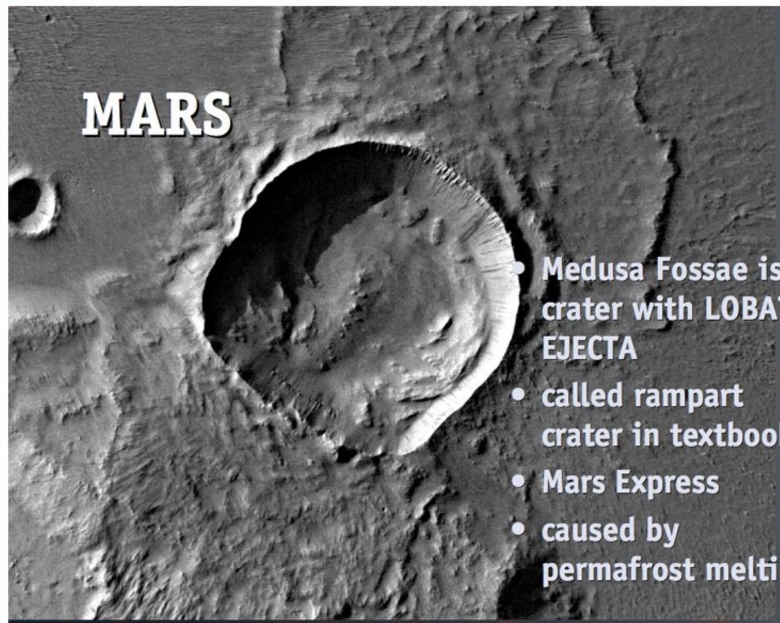


- Galileo orbiter image

COMET SHOEMAKER-LEVY/9

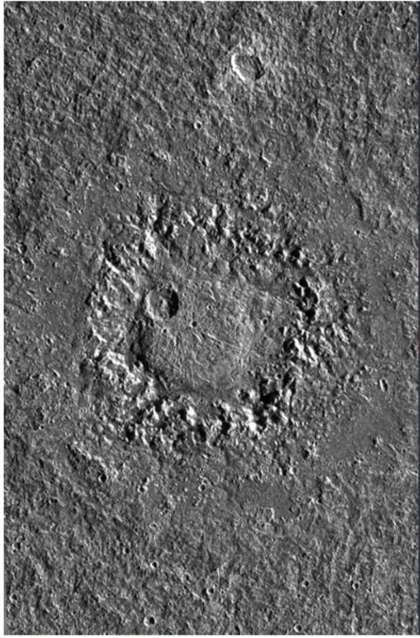


MARS



- Medusa Fossae is a crater with LOBATE EJECTA
- called rampart crater in textbook
- Mars Express
- caused by permafrost melting

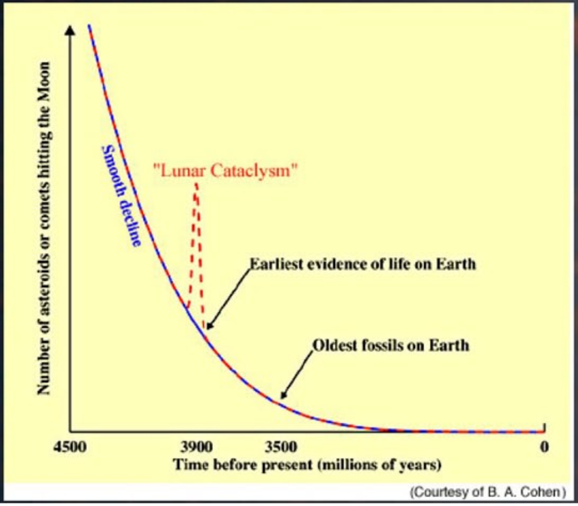
MEDUSA FOSSAE AGAIN



VISCOUS RELAXATION

- Ganymede crater
- weak/soft lithosphere, perhaps due to subsurface liquid
- also happens on Venus: lithosphere is soft because of high temperature

LATE HEAVY BOMBARDMENT



(Courtesy of B. A. Cohen)

- linked to giant planet migration?

Meteorites

Jason Utas

3 Types of Meteorites

- Stony
- Comprise ~90% of known meteorites.

- Iron
- Comprise ~8% of known meteorites

- Stony-Iron
- Comprise ~2% of known meteorites.

3 Typ

- Stony
- Compris

- Iron
- Compri

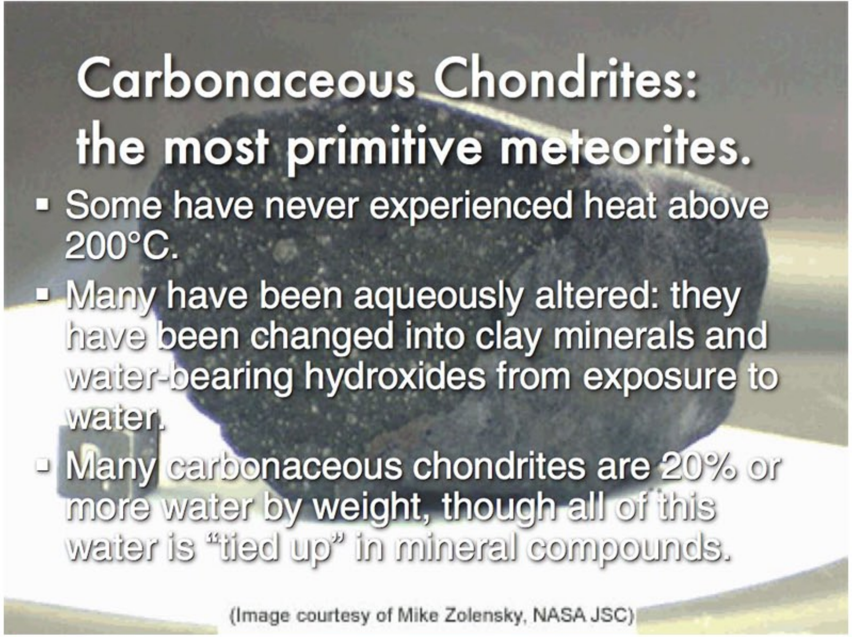
- Stony-Iron
- Comprise ~2

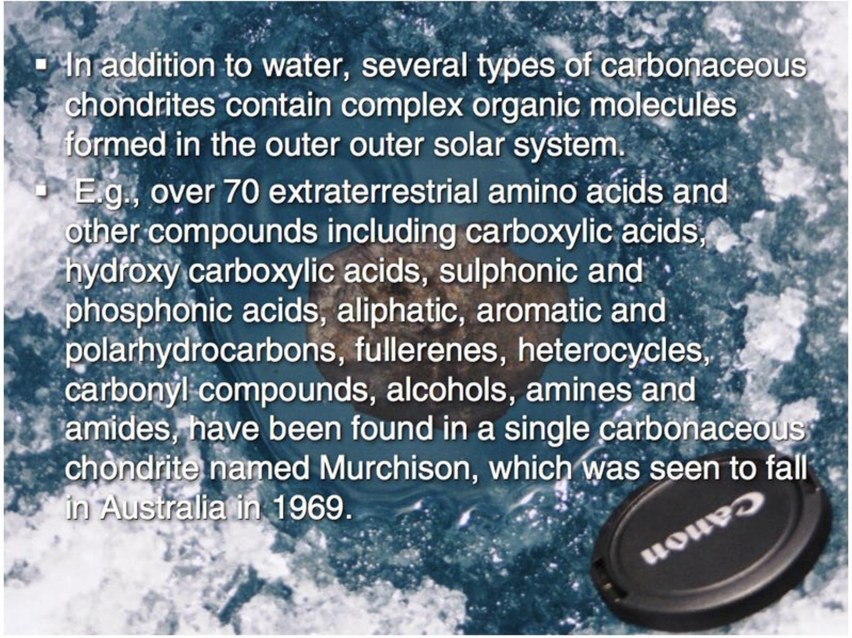
Stony Meteorites

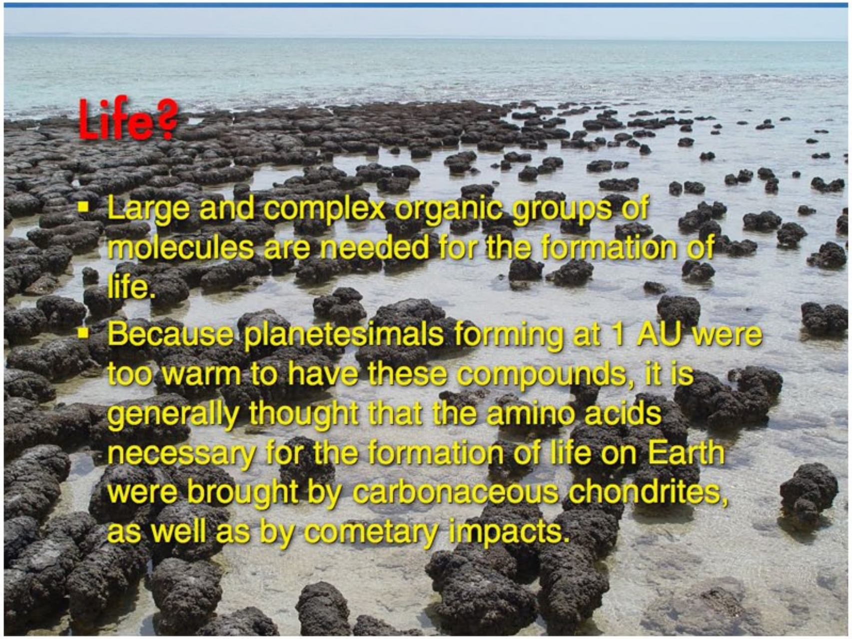
- Stony meteorites are divided into two main groups: chondrites and achondrites

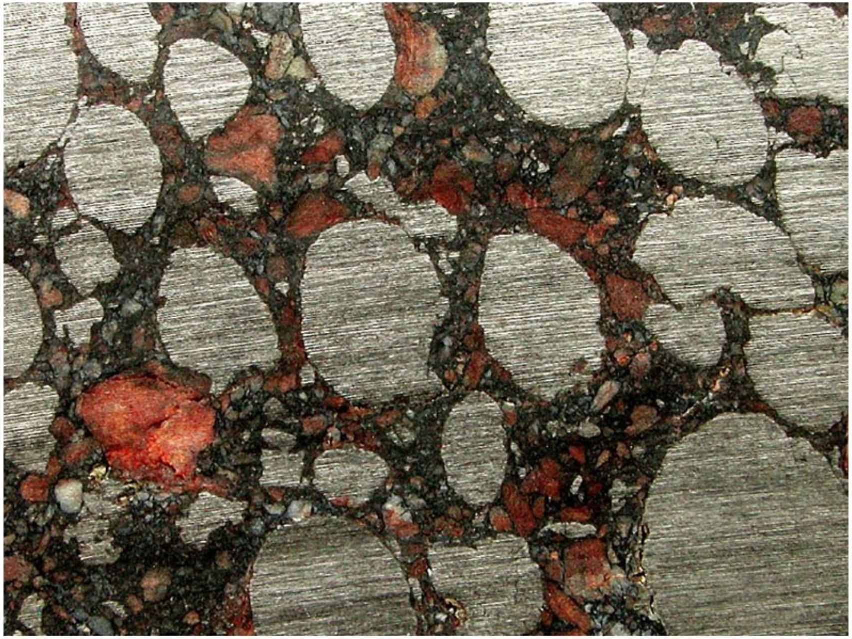
- Chondrites are the most primitive material known to exist within the solar system.
- Chondrules are the first droplets of solid matter to have condensed out of the gas surrounding our proto-sun.

- There are many different types of chondrites, but the most studied are the "carbonaceous chondrites."

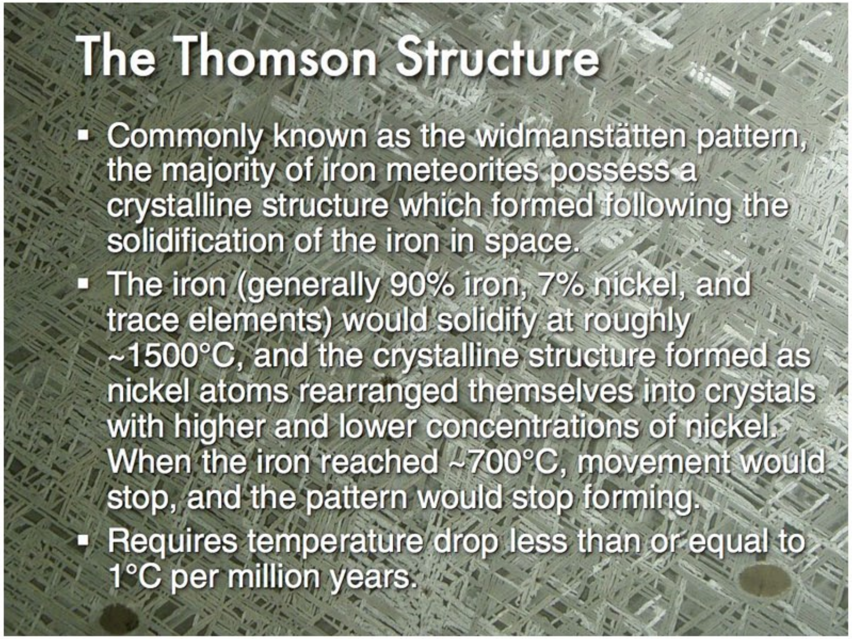

Carbonaceous Chondrites: the most primitive meteorites.
Some have never experienced heat above 200°C.
Many have been aqueously altered: they have been changed into clay minerals and water-bearing hydroxides from exposure to water.
Many carbonaceous chondrites are 20% or more water by weight, though all of this water is “tied up” in mineral compounds.
(Image courtesy of Mike Zolensky, NASA JSC)

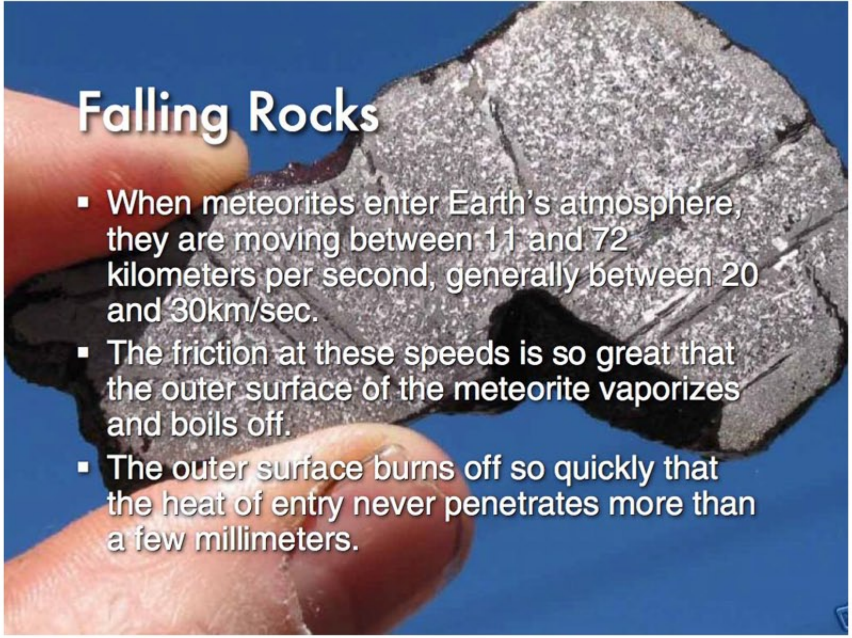

In addition to water, several types of carbonaceous chondrites contain complex organic molecules formed in the outer outer solar system.
E.g., over 70 extraterrestrial amino acids and other compounds including carboxylic acids, hydroxy carboxylic acids, sulphonic and phosphonic acids, aliphatic, aromatic and polarhydrocarbons, fullerenes, heterocycles, carbonyl compounds, alcohols, amines and amides, have been found in a single carbonaceous chondrite named Murchison, which was seen to fall in Australia in 1969.
Canon

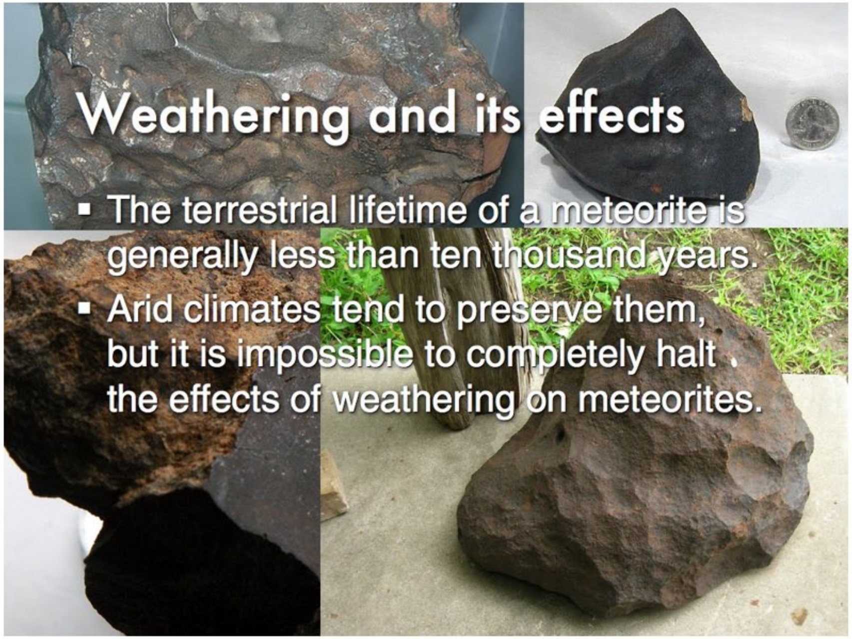

Life?
Large and complex organic groups of molecules are needed for the formation of life.
Because planetesimals forming at 1 AU were too warm to have these compounds, it is generally thought that the amino acids necessary for the formation of life on Earth were brought by carbonaceous chondrites, as well as by cometary impacts.




Iron Meteorites
Irons are remnants of large, differentiated solar system bodies which have been completely destroyed by impacts.
Whereas achondrites are samples of the surface of these large bodies, irons are fragments of their cores.


The Thomson Structure
Commonly known as the widmanstätten pattern, the majority of iron meteorites possess a crystalline structure which formed following the solidification of the iron in space.
The iron (generally 90% iron, 7% nickel, and trace elements) would solidify at roughly ~1500°C, and the crystalline structure formed as nickel atoms rearranged themselves into crystals with higher and lower concentrations of nickel. When the iron reached ~700°C, movement would stop, and the pattern would stop forming.
Requires temperature drop less than or equal to 1°C per million years.


Falling Rocks
When meteorites enter Earth's atmosphere, they are moving between 11 and 72 kilometers per second, generally between 20 and 30km/sec.
The friction at these speeds is so great that the outer surface of the meteorite vaporizes and boils off.
The outer surface burns off so quickly that the heat of entry never penetrates more than a few millimeters.


Weathering and its effects
The terrestrial lifetime of a meteorite is generally less than ten thousand years.
Arid climates tend to preserve them, but it is impossible to completely halt the effects of weathering on meteorites.