When was the last time most species were wiped out?

Meteoroid impacts on Earth

Approximate initial meteoroid diameter
- Every hour
- Every day
- Every year
- Every century
- Every millennium
- Every million years

Frequency of impact in Earth's lifetime
- Every 10,000 years
- Every million years
- Every 100 million years

Consequences
- Continues to cause region
- Wipes out global agriculture, growth of civilization
- Wipes out motor systems
Meteoroid impacts - impact rate

With time...

Early intense bombardment at close of planetary formation
→ planets sweeping up the debris

With location...

| TABLE 6.1 Rates of 2-km Crater Production of Various Planets Relative to Earth |
|----------------|----------------|----------------|
| Planet        | Minimum Value | Most Likely Value | Maximum Value |
| Mercury       | 0.5           | 1.3             | 3.3           |
| Venus         | 0.5           | 0.7             | 1.4           |
| Earth         | 1.0           | 1.0             | 1.0           |
| Moon          | 0.5           | 0.7             | 0.9           |
| Mars          | 0.6           | 1.3             | 2.6           |
| Outer planets | ?             | ?               | ?             |

Source: Data adapted from Hirtmann and others, 1981.

Estimates based on spacecraft estimates of micrometeoroid flux

Time-dependence of rates believed to be the same for all planets as all formed about the same time

Dating planetary surfaces

Crater saturation

- when the density of craters can no longer be increased

on ancient terrain of the Moon

Models show this is only possible for bodies that were around during the early intense bombardment

→ surface must be 3.9-4.4 Ga
Dating and cratering

The Moon

Nearside

Farside

Dark mare (seas)
- basalt similar to oceanic crust
- smooth plains
- 3.2-3.9 Ga

Light highlands (or uplands)
- fractionated igneous rocks
  - mostly plagioclase
- extensive impacts
- 4.5 Ga

1. Early chemical differentiation
2. Bombardment and mare formation
3. Surface quiescence

Crater counts and isochrons

uplands
4.5 Ga

mare
3.2-3.9 Ga
Crater counts and isochrons

What are the causes of the differences?

Magnetism on the Moon

No permanent magnetic field
• either no core
• or small core is now solid
  i.e. no dynamo

Small patches of remanent magnetism

Luna prospector, 1998
• Mapped magnetic field of the Moon
• Patches of remanent magnetism antipodal to young impact craters
  ➔ shock magnetization
Terrestrial planets
- primarily silicate planets

**Mercury**

**Difficult to observe**
- a little larger than the moon and close to the sun

**Highly cratered surface**
- early bombardment as on the Moon

**Few plains**

**Large core, thin mantle**
- (very high density)

Mariner 10 mosaic (1974-75)
Craters and ages
The Moon and Mercury

Mercury's magnetic field

Limited information
- only visited by one spacecraft: Mariner 10

Two (of the three) passes provide information on the magnetic field
- at 723 km max of 100 nT
- at 327 km max of 400 nT
- characteristics resemble Earth's magnetosphere

Estimated dipole moment: 2-5 x 10^{19} A m^2
~ 5 x 10^{-4} of the Earth's field ...weak

very strong remanent magnetism of the crust could produce this
...seems more likely this is the product of an active dynamo
Venus

Most similar to Earth?
• similar size and density
• believed to have a similar size core (no intrinsic magnetic field)
• might expect to observe plate tectonics

What would we expect to see?

Surface characteristics
• smooth
• random distribution of craters

Craters and ages

Surface characteristics
• smooth
• random distribution of craters
• 0.5–0.3 Ga

Global resurfacing event?
but no evidence of active tectonics today
**Venus and its tectonic-like features**

**Continents and subduction zones?**

- **Continental rift?**
  - broad dome 2km high
  - central rift 1-2 km deep

- **Shield volcanoes?**
  - basaltic composition (Venera 9 and 10)

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**No evidence of active tectonics today**

... remnants of past processes
Plate tectonics: Global bathymetry

Mars

Hemispherical asymmetry

low lying plains few craters

densely cratered highlands

1500 km diameter

2300 km diameter
Mars

**Olympus Mons**

Largest volcano in solar system
- 600 km diameter
- 26 km high
- broad shield volcano (Hawaii)

⇒ Lower gravity and stable location of convection with respect to lithosphere

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Craters and ages

Evidence of plate tectonics?
Magnetic field on Mars

- No global dipolar field
- Magnetic bands: 100 miles wide, 600 miles long
- Strength of the field ±1500 nT

What are we looking at?

Mars Global Surveyor, 1999

Correlation between topography and magnetic field

What are the relative ages of the Martian crust?

What does this mean for the dynamo?
Magnetic field on Mars

Mars Global Surveyor, 1999

What do the magnetic stripes mean?
Evidence of past plate tectonic motion?
Or, crustal deformation?

Stripes are ~100 miles wide: what are the implications for Martian plate tectonics compared to Earth?

What characteristic of the stripes would be strong evidence of plate tectonics?
Magnetic field on Mars

What do the magnetic stripes mean?
Connerney et al, PNAS 2005

Symmetric pattern observed along 0° meridian

Convinced?

EPS 122: Lecture 8 - Planetary dating, magnetism and tectonics?