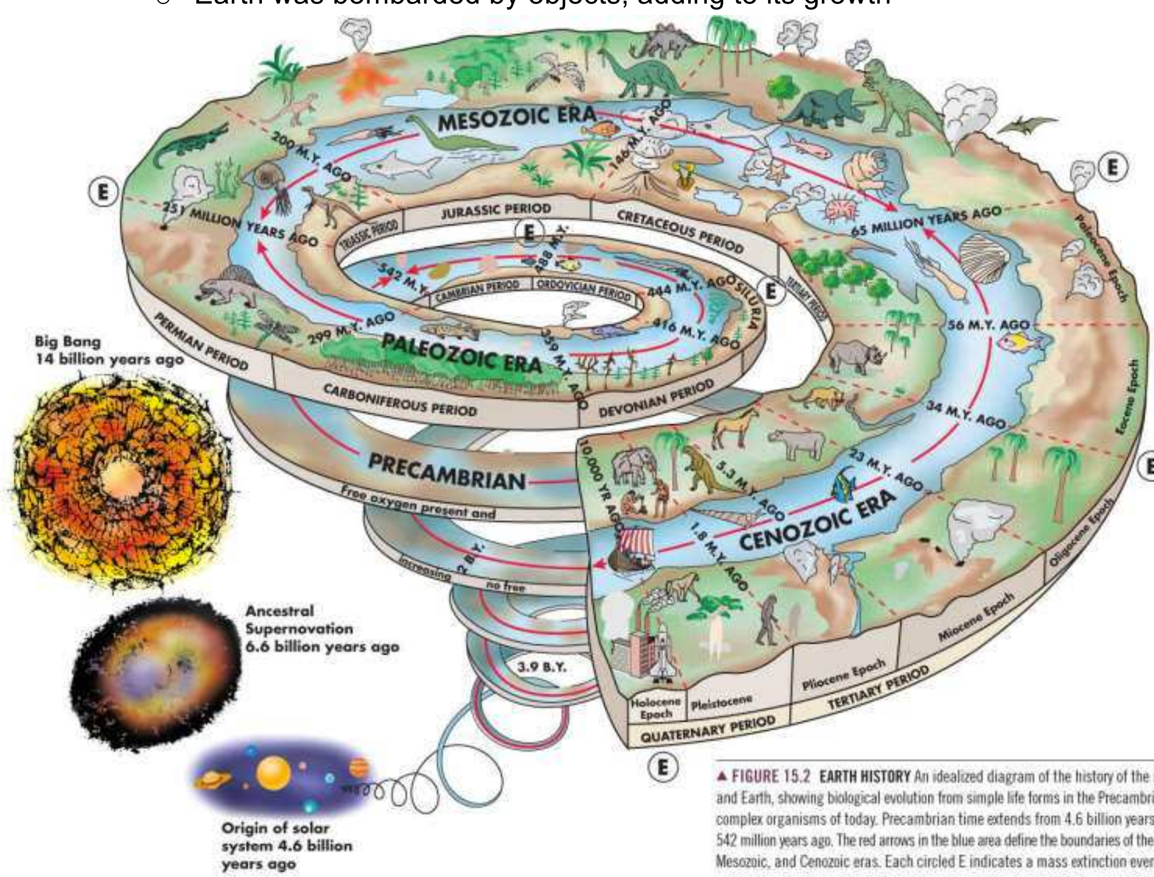
Lecture 13: Impacts and Extinctions

Earth's Place in Space

- The universe was created in an explosion known as the "Big Bang" 14 billion years ago
    - Explosion produced the atomic particles that later formed galaxies, stars, and planets
- First stars probably formed 13 billion years ago
    - The life span of a star depends on its mass
        - Large stars burn up more quickly ~ 100,000 years
        - Smaller stars, like the sun ~10 billion years
    - A supernova signals the death of a star
        - Release of huge amounts of energy
- A supernova triggered the formation of the sun 5 billion years ago
    - The sun grew grew by accretion of matter from a flattened rotating disk of hydrogen and helium dust called a solar nebula
- After formation of the sun, other particles were trapped in orbits around it
    - Particles in orbits attracted other particles until they condensed to form the planets and other objects that orbit the sun
    - Earth was bombarded by objects, adding to its growth



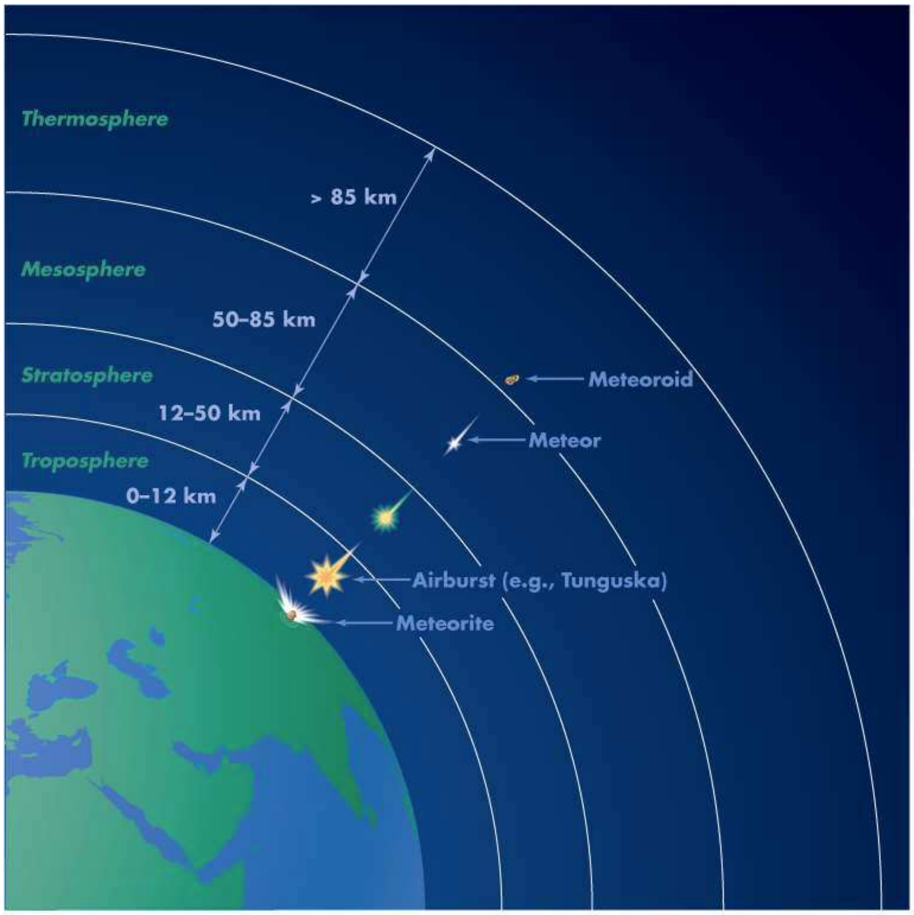
▲ FIGURE 15.2 EARTH HISTORY An idealized diagram of the history of the universe and Earth, showing biological evolution from simple life forms in the Precambrian to the complex organisms of today. Precambrian time extends from 4.6 billion years ago to 542 million years ago. The red arrows in the blue area define the boundaries of the Paleozoic, Mesozoic, and Cenozoic eras. Each circled E indicates a mass extinction event. *(Based on U.S. Geological Survey, International Commission on Stratigraphy, 2004, International Stratigraphic Chart; and Cloud, P. 1978. Cosmos, Earth and Man. New Haven, CT: Yale University Press)*

Asteroids, Meteoroids and Comets

- Particles in the solar system are grouped according to their size and composition
- Asteroid
    - 10m - 1000km in diameter
    - Consist of rock, metallic material, or mixtures of the two
    - Most are located in an asteroid belt between Mars and Jupiter
- Meteoroid
    - Smaller pieces of asteroids that range from dust to objects a few meters across
- Particles in the solar system are grouped according to their size and composition
- Meteor
    - A meteoroid that has entered Earth's atmosphere
    - Emits light as it moves through the atmosphere
- Meteorite
    - A meteor that strikes the Earth
- Comet
    - Has a glowing tail of gas and dust
    - Consist of a rocky core surrounded by ice and covered in dust

Airbursts and Impacts

- Extraterrestrial objects enter Earth's atmosphere at velocities of 12-72 km/s
- An object will either explode in an airburst at an altitude between a few kilometers and 50 km, or collide with Earth as a meteorite
- More than 175 meteorite craters have been identified on Earth's surface



◄ **FIGURE 15.8 THE FATE OF A METEOROID IN EARTH'S ATMOSPHERE** An idealized diagram showing what happens to a meteoroid when it enters Earth's atmosphere. Meteors are small dust- to sand-sized meteoroids that emit light in the mesosphere and stratosphere. A large meteoroid may break apart in an airburst or crash into Earth as a meteorite. *(Based on R. Baldini, http://www-th.bo.infn.it/tunguska/impact/fig1_2.jpg)*

Impact Craters

- Provide the most direct evidence of collisions
  - Bowl-shaped depressions with a pronounced upraised rim
  - Rims are overlain by an ejecta blanket
  - Broken rocks cement together into breccia
- Features of impact craters are unique from other craters
  - Impacts involve high velocity and extreme pressures and temperatures
  - Kinetic energy of impact produces a shock wave into Earth's crust
    - Compresses, heats, melts, and excavates rock
- Impact craters can be either simple or complex
- Impact craters are much more common on the moon for three reasons:
  - Most impact sites on Earth are in oceans
  - Impact craters on land have been eroded or buried
  - Smaller objects burn up and disintegrate in Earth's atmosphere
- The Shoemaker-Levy 9 comet impacted Jupiter in 1994
  - The comet consisted of 21 fragments, many with bright tails
  - Effects from the impacts included gas plumes and large rings in Jupiter's atmosphere around the impact sites

Simple Impact Craters
- Typically, small (a few kilometers in diameter)
- Do not have an uplifted centre

Complex Impact Craters
- Larger in diameter
  - Can be 100 km
- Rim collapses
- The center of the crater floor rises following the impact
- Most impact craters on Earth that are larger than 6km are complex

Mass Extinctions
- The sudden loss of large numbers of species of plants and animals
  - Coincide with boundaries of geologic periods or epochs
- Most hypotheses to explain mass extinctions involve rapid climate change caused by
  - Plate Tectonics
    - Create new patterns of ocean circulation
  - Volcanic Activity
    - Large eruptions release huge quantities of carbon dioxide, warming climate
    - Some eruptions release ash and sulphur dioxide, cooling climate
  - Extratenstrial Impacts
    - Release of dust blocks solar radiation

Major Mass Extinctions
- Geologists have documented 5 major mass extinctions during the past 550 million years
  - A sixth is occurring today due to increases in human population, deforestation, agriculture, overfishing, and pollution
- The first two extinctions could have been caused by global cooling followed by rapid warming
  - 446 and 250 million years ago
- The third might have been caused by volcanic activity
  - 202 million years ago
- The fourth extinction coincides with the end of the Cretaceous Period and the K-T boundary
  - 65 million years ago
  - Caused by the impact of a large asteroid
  - Brought an end to the large dinosaurs
  - The letter K is used because Cretaceous is spelled with a K in some languages
- The fifth extinction is linked to cooling and glaciation
  - 40 million years ago

- The current extinction began near the end of the Pleistocene Epoch

K-T Boundary Mass Extinction

- Dinosaurs disappeared with many plants and animals
  - 70% of all genera and their associated species died off
  - Some plants and animals were better adapted to the cooling that followed the impact
- How did scientists determine the extinction was caused by an impact?
  - Iridium was found in clay layers at the K-T boundary
  - Fossils found below this layer were not found above
  - How long did it take to form the clay layer?
    - Iridium deposits indicated that the layer formed quickly
    - Likely an extinction caused by a single asteroid impact
- The hypothesis was criticized because the researchers had no impact crater
- The crater was found in 1991 in the Yucatan Peninsula
  - Nearly circular, approximately 180 km in diameter, originally 30 to 40 km deep
  - About half of the crater lies beneath the Gulf of Mexico seafloor and the other half underlies sedimentary rocks
  - Sinkholes known as delineate the edge of the crater
  - Slumps and sedimentation have completely buried it
  - Drilling found impact breccia at the base of the crater fill
    - Tektite is a glassy melt rock indicates the intense heat that melted the rock

Risk Related to Impacts

- As long an asteroid remains in the asteroid belt between Mars and Jupiter, it poses no hazard to Earth
  - An asteroid's path can be disrupted by a collision
    - Path may then become elliptical and cross the orbital path of Earth, in which case it is called a near-earth object
- Consequences of an airburst or direct impact from an object several kilometers in diameter would be catastrophic
- Smaller impacts could kill millions of people if it occurred over or in a large city

Managing the Impact Hazard

- Identify objects in our solar system that could threaten Earth
  - Spaceguard Program
    - Study near-Earth objects with a diameter larger than 1 km
    - Uses telescoped with digital imaging devices to identify and monitor fast-moving objects
- Research to identify NEOs is likely to intensity in the future, with more objects catalogued and monitored

- Once a large near-Earth orbit object is known to be on a collision course with Earth, potions to avoid the effects are limited
    - Intercept the object and blow it apart
        - Small pieces could become radioactive and rain down on Earth
    - Divert the path of the object
        - Much more likely since we will have time to study the object
        - We have the technology to change the orbit of an asteroid
        - Small nuclear explosions would alter its path

TABLE 15.3 The Torino Impact Hazard Scale

No Hazard	0	Low collision hazard or object will burn up in atmosphere
Normal	1	Object will pass near Earth with collision extremely unlikely
Merits Attention by Astronomers	2	Somewhat close encounter; collision very unlikely and does not merit public attention
	3	Close encounter, with localized destruction possible; merits public attention if collision less than a decade away
	4	Close encounter with regional destruction possible; merits public attention if collision less than a decade away
Threatening	5	Close encounter with serious, but uncertain, regional destruction threat; merits contingency planning if less than a decade away
	6	Close encounter with serious, but uncertain, global catastrophe threat; merits contingency planning if less than three decades away
	7	Very close encounter with unprecedented, but still uncertain, global catastrophe threat; merits international contingency planning if less than a century away
Certain Collisions	8	Collision will occur with object capable of localized destruction on land or tsunami if close off-shore; once every 50 to 100 years
	9	Collision will occur with object capable of regional devastation or major tsunami; once every 10 000 to 100 000 years
	10	Collision will occur with object capable of global climatic catastrophe that threatens civilization; once every 100 000 years or more

Source: Based on Morrison, D., C. R. Chapman, D. Steel, and R. P. Binzel 2004. "Impacts and the public: Communicating the nature of the impact hazard." In M. J. S. Belton, T. H. Morgan, N. H. Samarasinha, and D. K. Yeomans (eds.). Mitigation of Hazardous Comets and Asteroids, *pp. 353–390. New York, NY: Cambridge University Press.*