Impacts from Space and Mass Extinction Events

OVERVIEW

To lay the foundation for better understanding of mass extinction events, we will first discuss Earth Science concepts such as the importance of the fossil record, the relationship between the biosphere and other Earth systems, and the frequency of extinctions through geologic time. We will then examine the evidence for the Cretaceous/Paleogene (Tertiary) (K/Pg) extinction and discuss possible causes for that extinction. We will also study the present likelihood of a mass extinction-causing meteorite impact by looking at meteor influx rates, sources of meteoroids, extinction periodicity, and historic meteorite impacts. Various mitigation strategies for impact hazards will be the topic of our final section.

INSTRUCTIONS and QUIZ

Study and make notes based on the online course material and the textbook reading assignments, and read the commentaries that follow. The review questions will allow you to assess your understanding of the key concepts.

This module will NOT be covered by any Quiz. You will be assessed on this Module only on the Final Exam. Consult the Final Exam FAQs for more information on the coverage of the exam.

LEARNING GOALS

Use the following learning goals as a self-assessment tool to help you gauge your understanding of the course material presented in this Module.

By the end of this Module, you will be able to:

1. Understand the concept of a biosphere and Earth System Science and that the biosphere has evolved over time
2. Distinguish between the oldest and youngest portion of a geological section using principles of superposition, original horizontality and cross cutting relationships
3. Describe the concept of faunal succession and the use of fossils in correlation and in the subdivision of Earth history
4. Recognize the qualities that make fossils useful in biostratigraphy
5. Identify important historical figures in the development of stratigraphy and biostratigraphy
6. Appreciate the scale of changes that can occur over geological time scales
7. List some of the major subdivisions /ages of the geological time scale and appreciate the relative scale between the Phanerozoic and the Precambrian

8. Understand how extinction events are linked to the structure of the geological time scale
9. List some of the major developments in the history of life on Earth
10. Define the characteristics of a mass extinction
11. List the "Big Five" mass extinction events and their order through time
12. Distinguish between broad extinction producing phenomena
13. Describe the late Ordovician and Permo-Triassic extinction
14. Describe the character of extinctions at the K/Pg boundary
15. Discuss the evidence used to support the K/Pg impact
16. Describe the location and probable nature of the K/Pg impactor
17. Describe the initial and long-term effects of the impact and their environmental consequences
18. Consider other potential causes of the K/Pg environmental collapse
19. Describe the type and location of potential impactors and rate of meteoroid influx
20. List some of the major impact features preserved on the Earth's surface and explain why impact craters appear to be rare on Earth
21. Describe some of the features and processes of crater formation
22. Provide examples of Canadian Impact Craters
23. Describe the hypothesis proposed by Raup and Sepkoski
24. List and describe some recent impacts and "near misses"
25. Understand the risk associated with an impact hazard
26. List possible mitigation strategies and appraise their relative effectiveness

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ORGANIZATION

Impacts from Space and Mass Extinction Events contains three units (A - C) that span the objectives listed above.

Unit	Topic
A	Extinctions - The Great Dyings
B	The Cretaceous/Paleogene (Tertiary) Extinction: A Case Study on Extinction
C	Impacts and Mankind

READINGS: Impacts from Space

Important Notes:
a) Don't memorize any Tables but understand the main points that the Tables illustrate.
b) Figures contain very important information, too! Read the captions and understand the ideas being illustrated

Read the following sections of **Chapter 12. The Great Dyings**:

- Brief history of life (pages 313-315
- Background extinction and mass extinctions (pages 317-318)
- Possible causes of mass extinctions (pages 318-323)
- Examples of mass extinctions (pages 323-327)

Read all of **Chapter 13. Hazards from Space** *except* the following sections:

- Space weather hazards (page 334-340)
- The great Canadian impact crater tour (pages 349-357)

In the textbook readings, all references to "Tertiary" actually refers to "Paleogene". All references to K/T should be replaced by K/Pg.

UNIT	TOPIC
A	Extinctions - The Great Dyings

Outline

1. The Earth's Changing Biosphere
2. Biostratigraphy
3. The Geological Time Scale
4. Mass Extinction Events: Definitions and Number
5. What Causes Mass Extinctions?
    - Biological Causes
    - Earth Based Causes
    - Extraterrestrial Impacts
    - Combination of Many Factors: The Permo-Triassic Extinction, A Case Study
6. Glossary of Terms/People

1. The Earth's Changing Biosphere

There are times when life on Earth has experienced severe crisis with many species going into extinction. In this unit we will examine the concept of a mass extinction, their frequency and possible causes.

A **mass extinction** is a crisis that affects life right across the planet from the deepest oceans to the highest mountains. It is helpful when trying to imagine such an event to consider all life on Earth as being part of the **biosphere**, a thin layer of life that exists on the surface of the planet that interacts with the hydrosphere (oceans, lakes and rivers), the atmosphere, and the lithosphere (the Earth's crust).

The biosphere has evolved through time. Consider the two ocean scenes in the figures below. Even though the creatures may look different in each figure, both demonstrate an active marine community and diverse biosphere.

Figure EX.1 A reconstruction of the Ordovician ocean, around 450 million years before present. Image by William B. S. Berry.

Figure EX.2 A reconstruction of a Cretaceous ocean, around 130 million years before present. Image by Karen Carr, with permission.

You can think of life and the biosphere as a play that has been running for millions of years in which the cast of actors has changed from time to time. The biosphere is composed of millions of individual species. As the components of the biosphere (individual species) evolve or go into extinction over time the biosphere evolves and changes.

CHECK YOUR UNDERSTANDING:

Which of the following statements is TRUE?
A) The lithosphere does not interact with the biosphere.
B) Ecosystems are only composed of land based creatures.
C) The biosphere is only composed of plants.
D) Plants often form the base of ecosystems.
E) The biosphere is composed of the atmosphere and the hydrosphere.

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2. Biostratigraphy

Life has evolved, changing the character of the biosphere through time. Appreciating this fact helps geologists and paleontologists measure the passage of geological time as recorded in the geological rock record.

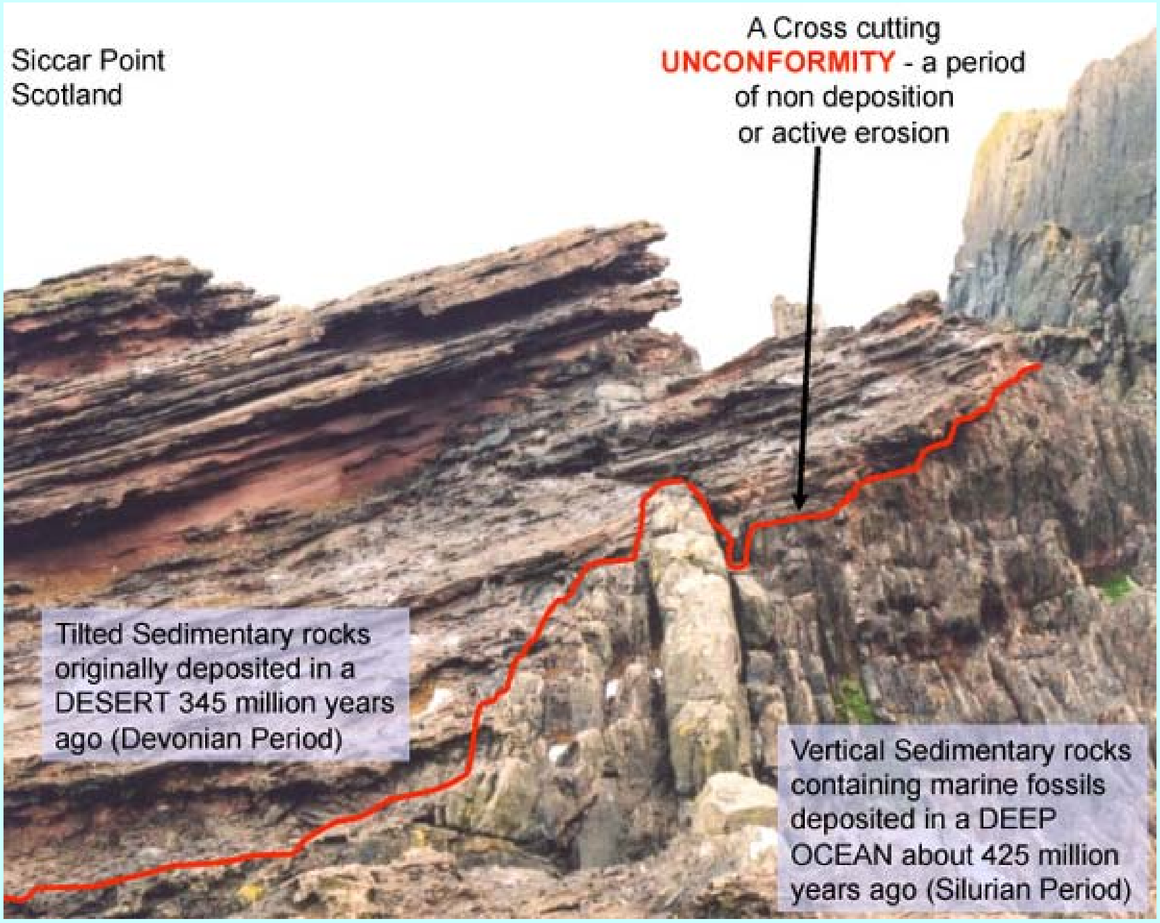
The following two concepts are vital to the interpretation of the geological record and the ancient biosphere (preserved as fossils) they contain.

1. **The principle of superposition**. This is a fundamental principle of stratigraphy (the study of rock layers) that was devised by Nicholas Steno in 1669. Basically, Steno states that in a succession of layered rocks, the rock layer at the bottom of the pile will be the oldest and the layer at the top the youngest. Effectively, "What's on top is youngest". In the figure below, the rocks at the bottom of the photograph will be older than those at the top.

Figure EX.3 A layered sedimentary rock at Stoer, NW Scotland. Photograph by Stuart Sutherland.

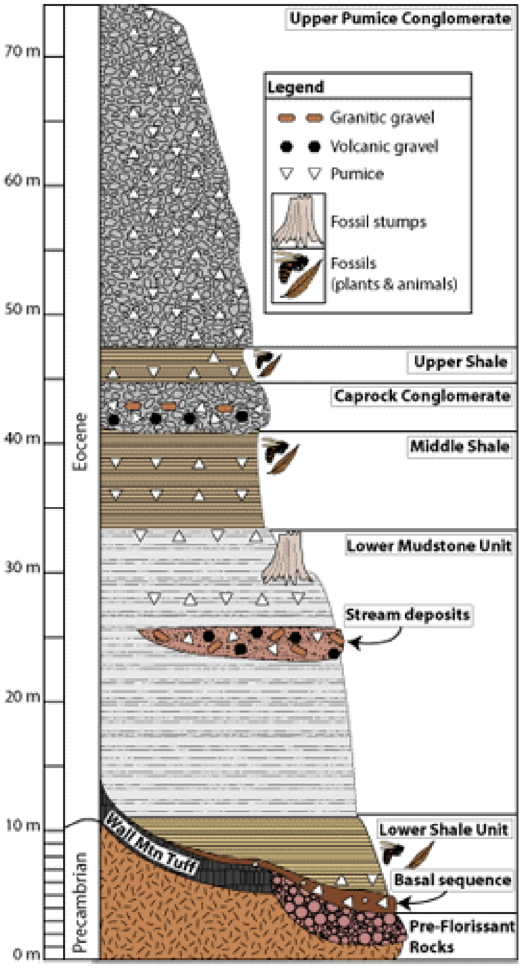
CHECK YOUR UNDERSTANDING:

The annotated image of Siccar Point, Scotland (below) describes important events in its geological history. Which event is the YOUNGEST?
A) the deposition of the desert rocks
B) the deposition of the deep ocean rocks
C) the tilting of the deep ocean rocks
D) the erosion of the deep ocean rocks to form the unconformity
E) it is impossible to tell



2. **Principle of faunal succession**. This was devised by William Smith in 1799 who recognized that strata of like age can be recognized by the fossils they contain even if the outcrops of strata are separated by large distances geographically. This only works because **species have evolved through time**. Using the appearance and disappearance of fossils to subdivide geological time is the science of **biostratigraphy**. Each fossil species is said to have a **range** through geological time. In other words, it exists in the geological record from the point that it evolves to the point that it becomes extinct.

Figure EX.4 A stratigraphic column of rocks in the Florissant area (Colorado, USA) illustrating the laws of superposition (the lower the layer, the



older) and faunal succession (older forms of life die out and new forms develop). Image from the Florissant Fossil Beds National Monument.

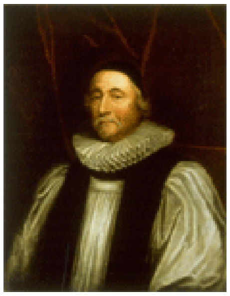
CHECK YOUR UNDERSTANDING:

1. The principle of faunal succession can be used to correlate rocks because ______. (select the MOST appropriate answer)
A) all sedimentary rocks were originally horizontal
B) the biosphere is composed of ecosystems
C) life and the biosphere have evolved over time
D) dinosaurs evolved in the Mesozoic
E) unconformities may cross-cut older rocks

2. Which of the following fossil ranges would provide the greatest RESOLUTION in biostratigraphy? A fossil species that ______.
A) is found throughout the Phanerozoic
B) is found throughout the Paleozoic
C) evolves and goes extinct in the Cretaceous
D) evolves in the early Mesozoic and goes extinct in the late Mesozoic
E) evolves in the Cretaceous and is still found today

3. The Geological Time Scale

By recording the sedimentary rocks and the fossils they contained, geologists in the late 1700s started to get the impression the Earth was very old. Previously the Archbishop of Armagh, James



Ussher (1581 - 1665, pictured on left) had calculated the Earth to be 6000 years old by adding up all the dates mentioned in the Bible. He arrived at a date of October 22, 4004 BC for the creation of planet Earth. Not only was the concept of an ancient Earth difficult to accept by many people, so was the concept of extinction. To entertain the idea that creatures had gone extinct was to suggest that God's creation was incomplete. George Cuvier (1769 - 1832) examined the remains of mammoths in Europe concluding they were a **once living** species that had become **extinct**.

During the late 1700s and 1800s scientists started to conclude that the Earth is ancient and had undergone much change throughout its history. This includes dramatic changes in the types of creatures that inhabited the planet.

Gradually, geologists and paleontologists started to construct a geological time scale to represent the changing character of the Earth through time. Fossils were used to correlate between different regions and characterize particular periods of Earth's history.

CHECK YOUR UNDERSTANDING:

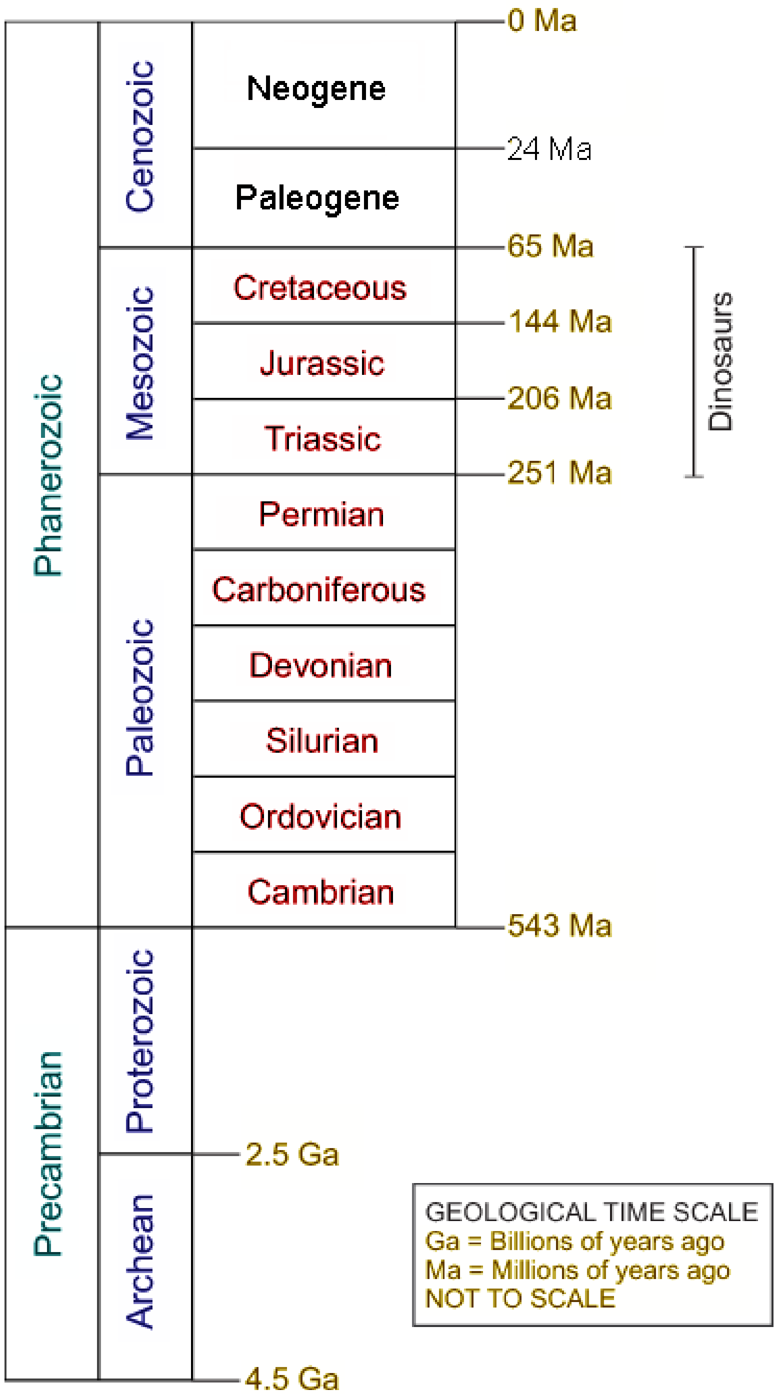
Who of the following believed the Earth to be around 6,000 years old?
A) Cuvier
B) Ussher
C) Hutton
D) Steno
E) Smith

Today we have a time scale that divides and subdivides Earth's 4.6 billion years into various time periods (see figure below). Let's look at details of this time scale (see figure below). In the figure, the subdivisions of time are called (from the left most column to the right) **Eons** Precambrian and Phanerozoic), **Eras** (Archean, Proterozoic, Paleozoic, Mesozoic, and Cenozoic), and **Periods** (from the oldest, Cambrian, to the most recent, the Quaternary).

- Note that the **Precambrian**, when compared to **Phanerozoic**, is far less subdivided even though it represents the majority of Earth's history. This is due to an extraordinary proliferation of fossils at the base of the Phanerozoic in a period called the **Cambrian**.

  It was here that most of the creatures with hard parts like shells, teeth, and internal skeletons evolved. Fossils with hard parts fossilize much more readily than soft-bodied creatures. So, in addition to an increasing biodiversity as new species evolved, many of the new "hard part creatures" would more readily form fossils. Consequently the Phanerozoic is more finely subdivided that the Precambrian.

Figure EX.5 Geologic timescale in millions of years ago (Ma) based on superposition of sedimentary rock layers and irreversible succession of fossils. Image ©Stuart Sutherland.



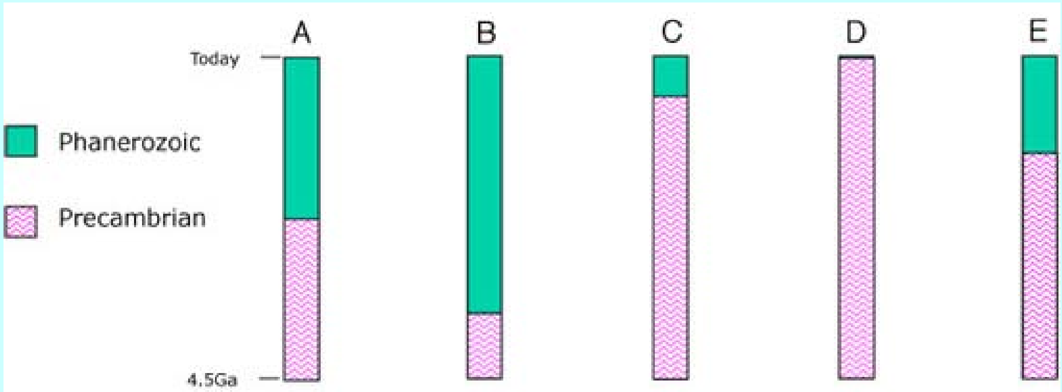
- **Eras** are broad subdivisions that are particularly significant. They represent a grouping of geological periods. These major groupings are not placed arbitrarily but represent times when there has been a **major change in the Earth's biosphere**.

- As mentioned above, the base of the Phanerozoic is defined by the emergence of creatures with hard parts. The base of the Mesozoic and the Cenozoic, however, are based on the **emergence of new species following a mass extinction** at the top of the Paleozoic and Mesozoic respectively.

- The base of all periods is defined on the emergence or **radiation** of new species.

CHECK YOUR UNDERSTANDING:

1. Which of the following would best represent the relative distribution of time between the Precambrian and the Phanerozoic?



2. Which of the following events in Earth's geological history could NOT have occurred over a 200-million year period?
A) opening and closing of oceans
B) fragmentation of supercontinents
C) evolution then extinction of whole groups of species
D) sediments being turned into rock, tilted, then eroded
E) ALL of these processes/events could occur over a 200-million year period

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4. Mass Extinction Events: Definitions and Number

Species are going extinct all the time. In fact, extinction is the expected fate of a species. There are various definitions of what constitutes a **mass extinction** but the following would be agreed by most to represent such an event.

a. **At least 30%** of Earth's species must be lost
b. It must be across a **broad range of ecologies**, not restricted to any one niche.
c. It must have a **short/sudden duration** (around 1 million years maximum).

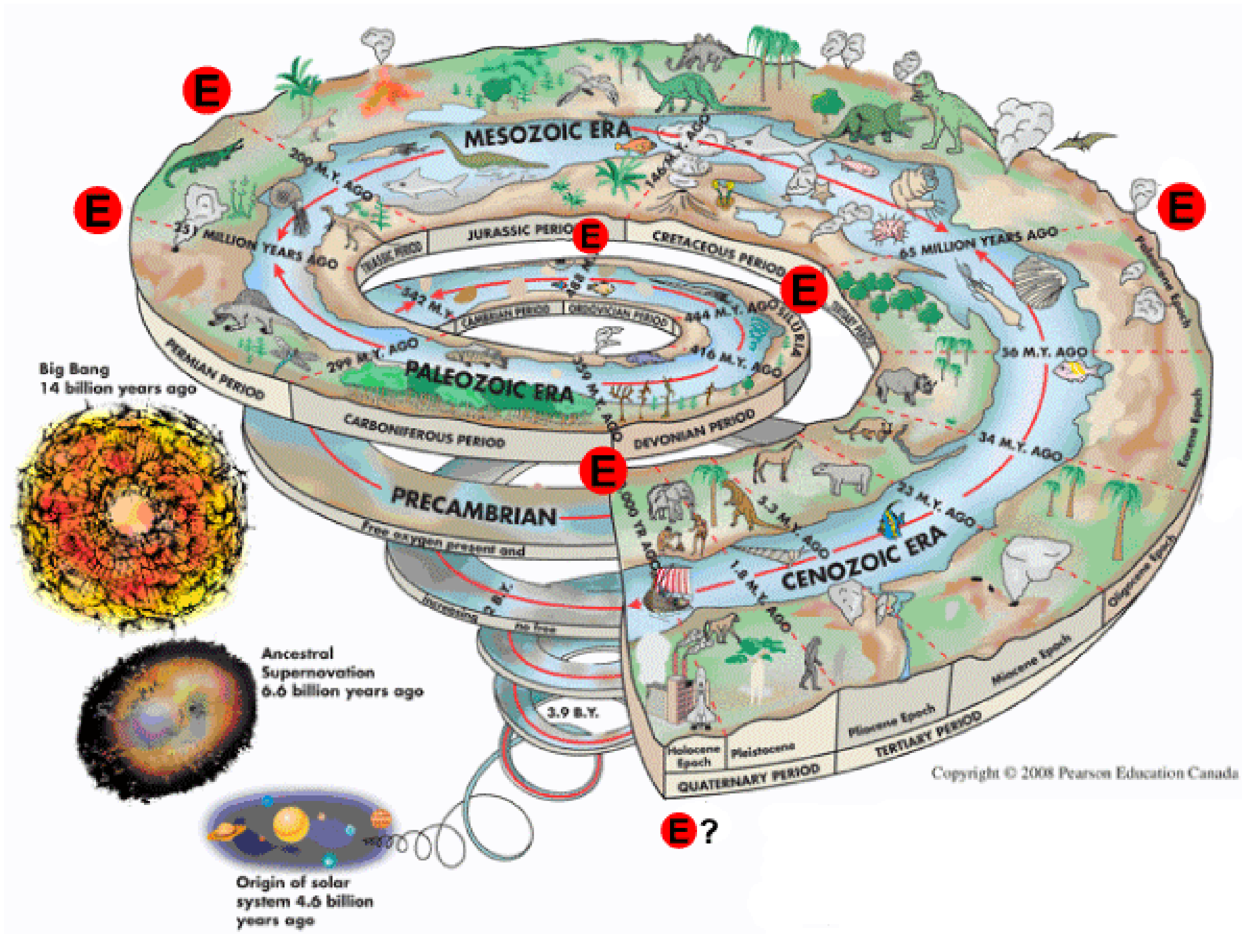
CHECK YOUR UNDERSTANDING:

Which of the following would be considered a MASS EXTINCTION? The extinction of ______.
A) all ladybug species over 10 years
B) 20% of all species over 90,000 years
C) 80% of species over 10 million years
D) 90% of species in temperate rain-forests
E) 45% of all species over 500,000 years

There have been at least 5 major extinctions (the "Big Five") in the Phanerozoic (see figure below):

- Cretaceous / Paleogene (Tertiary) (K/Pg), 65 Ma
- Late Triassic, 205 Ma
- Permo / Triassic, 251 Ma
- Late Devonian, 360-375 Ma

- Late Ordovician, 440-450 Ma



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. Each red-encircled E indicates a mass extinction event (large ones indicate the "Big Five"). Many biologists view the present era as part of a mass extinction event (the Holocene extinction event), possibly one of the fastest ever. The "?" alongside the smaller, red-encircled E indicates that paleontologists, however, question whether the available data support a comparison with mass extinctions in the past. Figure from *Keller et al., 2011*.

CHECK YOUR UNDERSTANDING:

1. Which of the following global event is used to DEFINE the end of the Mesozoic?
A) a large impact crater
B) a change in climatic conditions
C) a period of intense cold followed by a period of very warm conditions
D) the death of the dinosaurs
E) the extinction of many species and subsequent radiation of new species in the Paleogene

2. Which pair of extinction events "bracket" the time of the dinosaurs?
A) Late Ordovician and Permo-Triassic
B) Late Devonian and Late Triassic
C) Permo-Triassic and Cretaceous-Paleogene
D) Late Devonian and Cretaceous-Paleogene
E) Late Devonian and Permo-Triassic

5a. Biological Causes of Mass Extinctions

Organisms being brought together that once lived in isolation can cause mass extinctions. For example, many of the New Zealand ground dwelling bird fauna were devastated when human hunters and then later European mammals (cats, rats, dogs) were introduced.

The three main modes of a biologically induced extinction are:

i. **Competition** between creatures occupying the same ecological niche

ii. (excessive) **Predation**: Predators do not have to do the whole job, just drive a population to a low enough level then "random extinction" can complete the extinction. The idea behind a random extinction is that, although the number of individuals in a species may grow and the species may spread over a wide area, nothing ensures the permanent survival of a species.

iii. **Pathogens**: disease being introduced to an area by incoming plants or animals

5b. Earth Based Causes of Mass Extinctions

Extinctions influenced by Earth-based tectonic processes may be caused by changes in continental configuration or changes in atmospheric composition.

i. **Changes in continental configuration.** Changes in the distribution of continents can have a profound effect. Two major effects of continental configuration are detailed below.

a. **Changes in climate, ocean cyclicity, sea level**. Weather patterns and the movement of the oceans are directly linked to the distribution of continents.

> ***FOR EXAMPLE*: The Late Ordovician extinction**
>
> Gondwana (a continent consisting of South America, Africa, Antarctica, India, and Australia; see figure below) moves below the South Pole during the late Ordovician causing a severe ice age. As water was locked up in the form of glaciers at the Southern Pole, sea level fell. This may have had a severe effect on creatures that lived in the shallow water close to the continental margins. As the sea retreated off the continental shelf and into the ocean basins, shallow marine ecosystems would have been devastated.

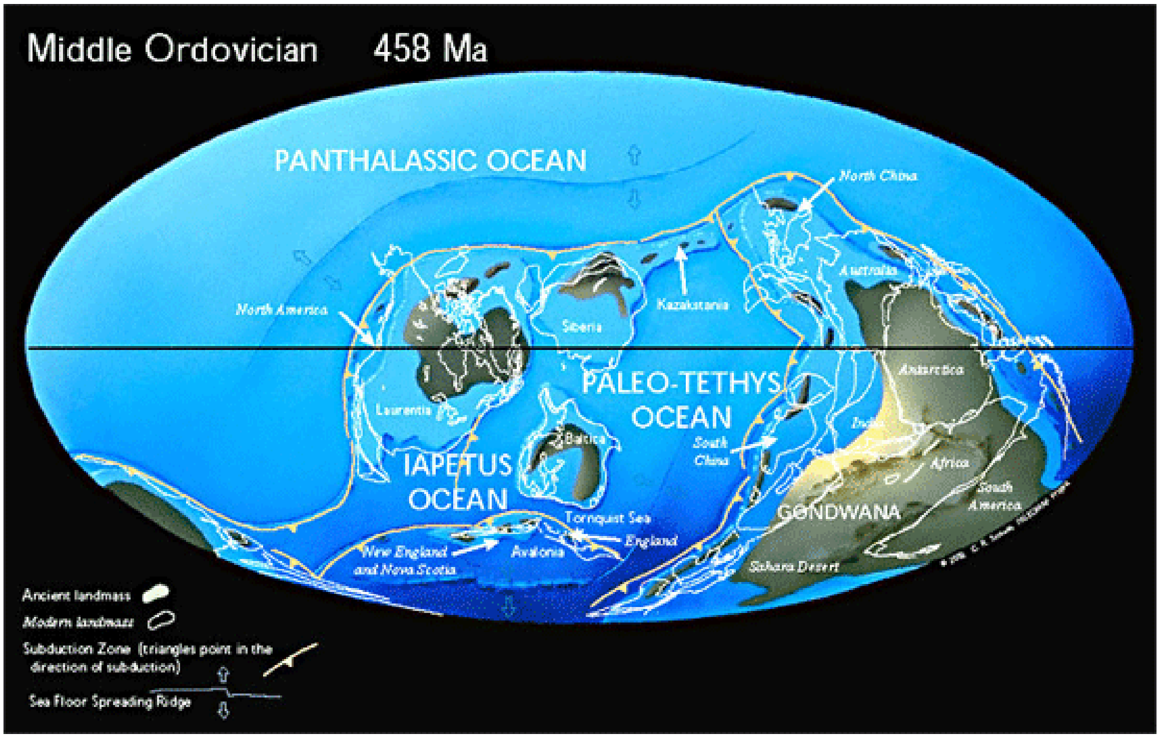


Figure EX.6 Distribution of continents during the middle Ordovician before it slipped below the south pole during the late Ordovician. Plate tectonic map and by C. R. Scotese, PALEOMAP Project.

b. **The greater the landmass the lower the diversity**. At the moment we have a relatively high biodiversity. This is in part due to the number of continents that are in effect isolated from one another. In times when there is a high degree of continental fragmentation, evolution can proceed in isolation to produce many different species on different landmasses. If plate tectonics causes the formation of a large interconnected land mass there will be more competition between species and lower biodiversity.

***FOR EXAMPLE*: The Permo / Triassic Extinction**

At the end of the Permian, plate tectonics had brought all the continents together to form the super continent of Pangaea (see figure below).

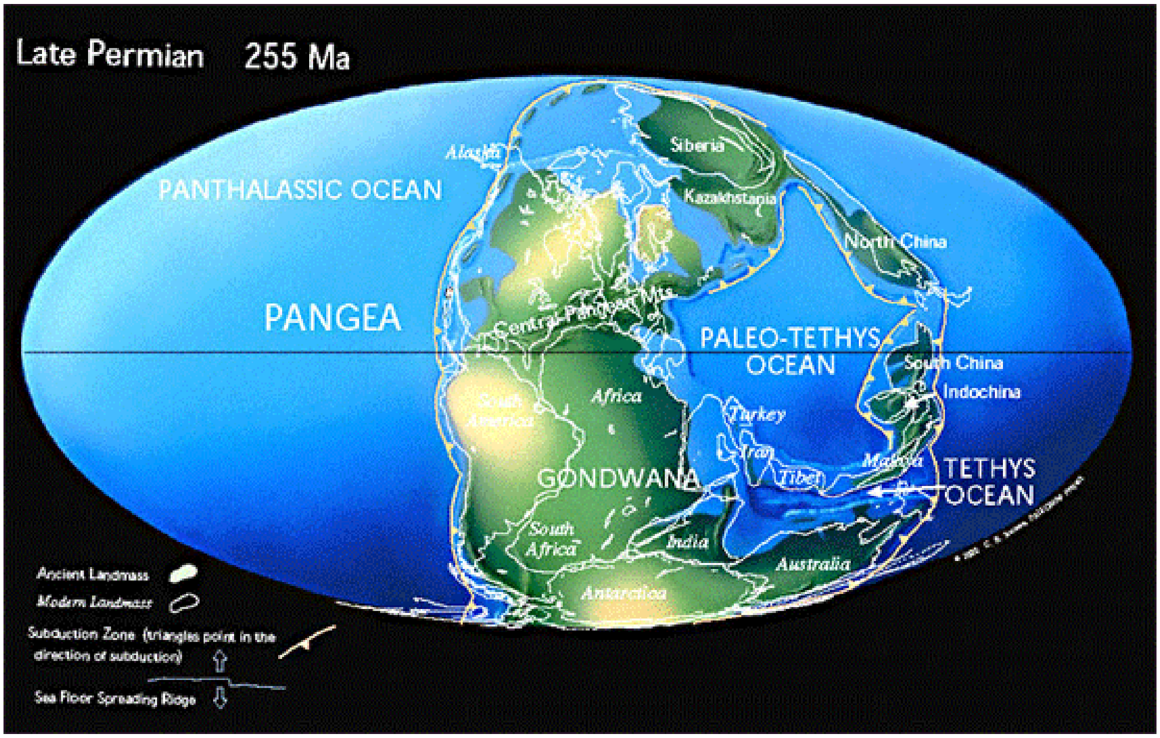


Figure EX.7 The supercontinent of Pangaea during the late Permian. Plate tectonic map and by C. R. Scotese, PALEOMAP Project.

ii. **Changes in the atmosphere.** In addition to the climatic effects due to continental configuration, volcanic activity can also have severe effects. Gases such as carbon dioxide can cause greenhouse warming and aerosols may cause climatic cooling. These can significantly affect the health of the biota.

CHECK YOUR UNDERSTANDING:

Which of the following would NOT be considered a "Physical Earth-based" cause for a mass extinction event?
A) an extremely extensive volcanic event
B) warming of the atmosphere due to an increase in greenhouse gases
C) decreased circulation of the oceans
D) spread of a virus that kills 90% of plant life
E) extensive glaciation of all major continental areas

5c. Extraterrestrial Impacts: Cause of Mass Extinctions

This topic will be discussed in a later section.

5d. Combination of Many Factors: The Permo-Triassic Extinction, A Case Study

It is very unlikely that any one factor would be responsible for a global crisis in the biosphere. Combination of events and circumstances are generally recognized as being the cause of mass extinction events.

The Permo-Triassic Extinction: The WORST "day" for the Biosphere, 251 million years ago. During this extinction event, between **95 - 98%** of all species would go into extinction. It hit both ocean- and land-based ecosystems and was less than 1 million years in duration. Many of the common Paleozoic marine creatures would suffer badly through this extinction including **trilobites**, **brachiopods,** and **crinoids**. On land, large amphibians and mammal-like reptiles would be badly effected.

What were the causes of the Permo-Triassic extinction? The most likely scenario for any mass extinction event involves a number of events coming together at the same time. That was certainly true for the Permo-Triassic. The list of potential causes that follows is certainly not exhaustive and many of the points are probably interrelated.

1. **Continental configuration: drop in biodiversity.** As discussed previously, the greater the landmass the greater the competition between species. At the end of the Permian, the supercontinent of Pangaea or "all lands" would have brought many species into direct competition.

2. **Sea level fall: less ocean ridge activity.** Sea floor spreading slowed its pace during the Permian. As a result, the oceanic ridges were smaller in size and displaced less water. Consequently oceans retreated from shallow areas into the deeper basin causing problems for creatures that lived in any remaining shallow marine environments.

3. **Oceanic stagnation.** The close of the formation of Pangaea saw the end of an ice age. Cold polar waters probably disappeared and ocean circulation slowed or stopped. This would have reduced ventilation of deep ocean waters killing off many deeper marine species. In addition occasional overturn of stagnant water could have brought oxygen poor waters to shallower marine communities as well.

4. **Climate change.** Due to the formation of a large landmass, climate would have been much drier and subject to drought.

5. **Siberian Traps: massive volcanic activity in Russia.** Around 2 - 3 million km^3 basaltic lava were produced within a million years. Carbon dioxide from the volcanic activity and methane caused by melting of gas hydrates would have resulted in greenhouse warming of the planet. In addition, gas emission from volcanoes would have also produced acid rain effects.

6. **Possible impacts.** Although still very controversial, it is possible that the Earth suffered impacts from space during this time as well.

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6. Glossary of Terms/People

anoxia
: a lack of oxygen

atmosphere
: layer of gases surrounding the lithosphere

biodiversity
: the number of different species

biosphere
: global sum of all ecosystems

biostratigraphy
: correlation of rocks using fossils

Cambrian
: oldest period of the Phanerozoic / Paleozoic

Cenozoic
: the most recent grouping of geological periods in the Phanerozoic

correlation
: matching geological sections that might be separated by large distances

Cretaceous
: youngest period of the Mesozoic

Cross-Cutting Relationships

method of deduction of relative age of geological sections

Cuvier, George

established concept of extinction

Deep Time

understanding the extreme age of Earth

Devonian

geological period in the Paleozoic

Earth System Science

understanding Earth as an interaction of many systems (spheres)

ecosystem

a collection of living organisms that interacts with the Earth System

evolved/evolution

theory to explain biodiversity and emergence of new species

extinct/extinction

death of every member of a species

Faunal Succession

change in fossil species over time

flood basalt

basalt lava produced by large scale volcanic activity

foraminifera

microfossils that commonly secrete a calcium carbonate shell

fossil range

length of geological time a species existed on Earth

Ga

Giga annum: billions of years ago

glaciation/glacial period

cold climatic periods marked by the advance of glaciers

Gondwana

southern part of Pangea

greenhouse gas

gases in the atmosphere that contribute to global warming

Hutton, James

Scottish Geologist; used cross cutting relationships in Earth age studies

hydrosphere

all Earth's liquid water

lithosphere

outer layers of the Earth including the crust and uppermost mantle

Ma

Mega annum: millions of years ago

Mesozoic

grouping of geological periods: oldest Triassic, youngest Cretaceous

microfossils

all fossils just at the limit or smaller than can be seen by the naked eye

Ordovician

a period in the Paleozoic

Original Horizontality

a stratigraphic principle

Paleogene

oldest geological period of the Cenozoic

Paleozoic

a grouping of geological periods; the oldest grouping of the Phanerozoic

Pangea

large landmass that existed during the Permian

periods

geological time divisions

Permian

a geological period; youngest period in the Paleozoic

Phanerozoic

grouping of all geological periods after the Precambrian

Precambrian
: grouping of all geological periods older than the Cambrian/Phanerozoic

radiation
: the emergence of new species following a mass extinction event

Smith, William
: English engineer who developed the concept of faunal succession

Steno, Nicholas
: Danish anatomist who developed the principles of stratigraphy

strata
: layers of sedimentary rocks or lava flows

stratigraphy/stratigraphic
: study of the manner in which strata are laid down

supercontinent
: a landmass comprising of more than one continental core

Superposition
: stratigraphic principle which says “What is on top is youngest”

Triassic
: youngest geological period of the Mesozoic

Unconformity
: an erosion surface separating two rock masses of different ages

Ussher, James
: Archbishop of Armagh who believed Earth was created in 4004 BC

UNIT	TOPIC
B	The Cretaceous - Paleogene Extinction, A Case Study on Extinction

Outline

1. The K/Pg (formerly K/T) Extinction Event
2. Louis and Walter Alvarez and the K/Pg Impact
3. Further Evidence To Support Impact
    - Fern Spores vs. Pollen
    - Tektites
    - Shocked Quartz
    - Tsunami Deposits
4. The Chicxulub Impact Crater
5. Consequences of the Chicxulub Impact
    - Initial Effects
    - Longer Term Effects
6. Is the Chicxulub Impact Crater the Smoking Gun?

1. The Cretaceous - Paleogene (K/Pg) Extinction Event

At the end of the Cretaceous, many creatures, including the dinosaurs, went into extinction. In this unit we will examine the nature of and possible causes of this extinction.

Just as the end of the **Permian** extinction marked the beginning of a new grouping of periods (the **Mesozoic**) the end of the **Cretaceous** extinction is likewise so distinct that it marks the beginning of the latest grouping of periods, the **Cenozoic**.

Over 50% of all species on the planet would go into extinction during the K/Pg extinction event. On land, few creatures over 25 kg in weight would survive. In general the extinction was even more severe in the oceans with around 80 - 90% of marine species including the ammonites and marine reptiles going into extinction.

Figure EX.2 A reconstruction of a Cretaceous ocean, around 130 million years before present. Digital image by Karen Carr, with permission.

CHECK YOUR UNDERSTANDING:

Which of the following statements regarding the degree of extinctions around the K/Pg boundary is TRUE?
A) Over 95% of species went into extinction.
B) All creatures larger than 25 grams went into extinction.
C) Around 80 - 90% of marine species went into extinction.
D) It only effected land based creatures.
E) It only effected ocean based creatures.

2. Louis and Walter Alvarez and the K/Pg Impact

In addition to being famous for the death of the dinosaurs, the K/Pg is also well known for its association with a major extra-terrestrial impact event. This feature of the K/Pg extinction was brought to the attention of the world by a father and son scientific team, Louis and Walter Alvarez.

The Alvarez team was investigating a clay layer that occurs in a geological section that crosses the K/Pg boundary in Gubbio, Italy. The 1-cm clay layer lies directly on top of the latest Cretaceous rocks and was found to be enriched in the element **iridium**. Iridium is very rare at the Earth's surface and yet in this layer was enriched over 300× above background. This **iridium anomaly** has now been recorded in many other sections around the world that straddle the Cretaceous/Paleogene boundary.

Iridium is known to exist in higher concentrations in extra-terrestrial objects such as asteroids. Alvarez suggested that the clay layer enriched in iridium has been produced by a meteor or comet over 10 km in diameter impacting the Earth. He suggested further that this impact may have also been responsible for the extinction at the end of the Cretaceous.

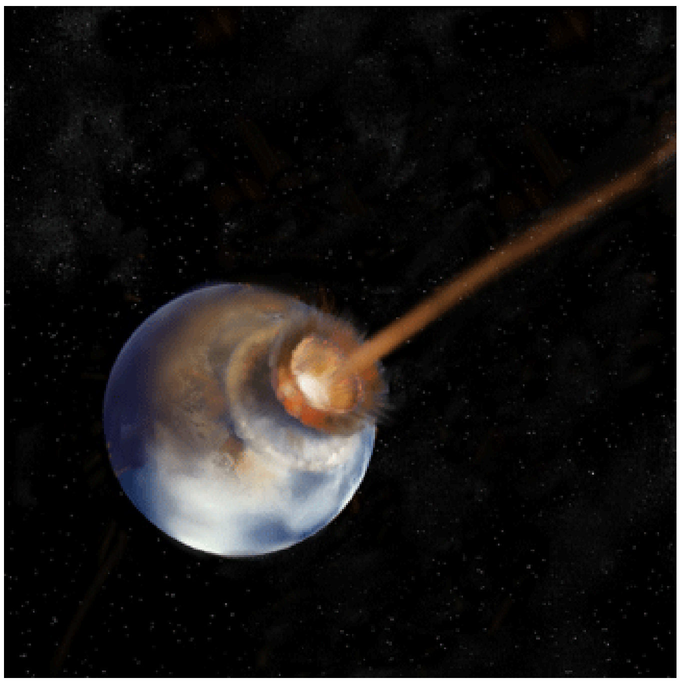

Figure EX.8 Impact Earth. An artist's conception of an extra-terrestrial object impacting the Earth. Digital image by Karen Carr, with permission.

3. Further Evidence To Support Impact

Scientists were very excited about the possibility of a major impact in Earth's past but required additional evidence to support the proposal. The following are just some of the evidence used to support the hypothesis.

3a. Fern Spores vs. Pollen

Ferns are often the first plants to colonize a landscape that has been devastated by fire. In the earliest **Paleogene** (part of what was formerly called the Tertiary), many areas show an increase in fern spores relative to pollen (see figure below). This suggests that global forest fires may have raged at the end of the Cretaceous leaving a landscape open for ferns to spread. This is further supported by high concentrations of soot found around the K/Pg boundary.

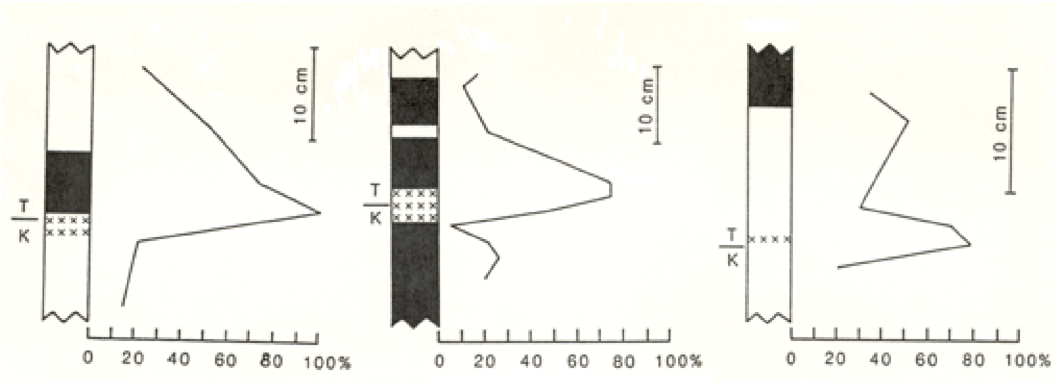

Figure EX.9 Fern-spore relative abundances from three K/Pg boundary localities in the Raton basin. Left: Starkville North section, Colorado. Middle: Sugarite section, New Mexico. Right: Raton Pass section, New Mexico. (Black = coal; white = mudstones and shales; xxxx = K/Pg boundary claystone; T = Tertiary, former term that included the Paleogene; K = Cretaceous). Figure from USGS.

CHECK YOUR UNDERSTANDING:

If you were looking for evidence of ancient major global forest fires, what might you expect to find in the sediments?
A) high concentrations of iridium
B) a high proportion of fern spores
C) the quartz in the sediments would show "cross-hatched" features
D) a high proportion of pollen
E) tear- or hershey kiss-shaped structures composed of natural glass

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3b. Tektites

Tektites are thought to be produced during an impact event. They are composed of natural glass. During impact, rock is melted and ejected from the crater. As it travels through the air and cools, it forms characteristic aerodynamic shapes. Many tektites are found at the K/Pg boundary in many different locations, again suggesting a massive impact event.

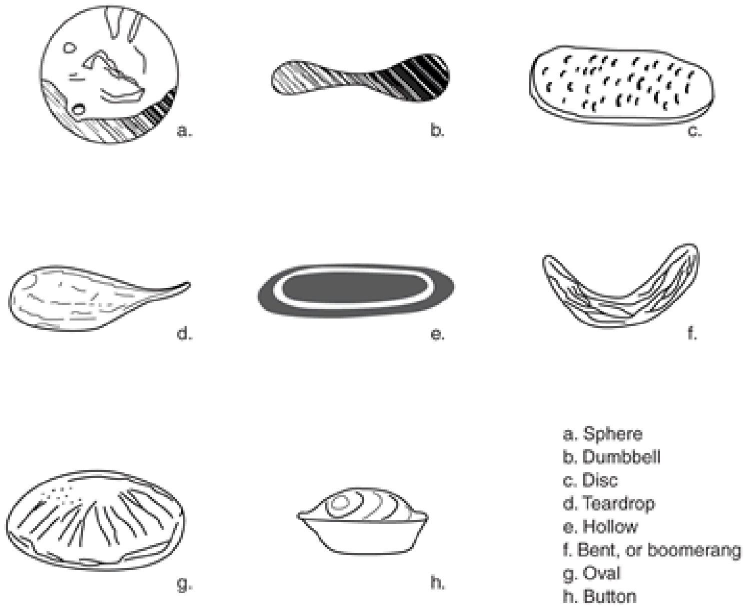

Figure EX.10 Tektite shapes. Figure from the Australian Museum.

3c. Shocked Quartz

In many sections around the K/Pg boundary, fragments of the mineral **quartz** show evidence of multiple fractures. These fractures are thought to be produced when rock is shattered during a high-energy impact. The fragments are called **shocked quartz**.

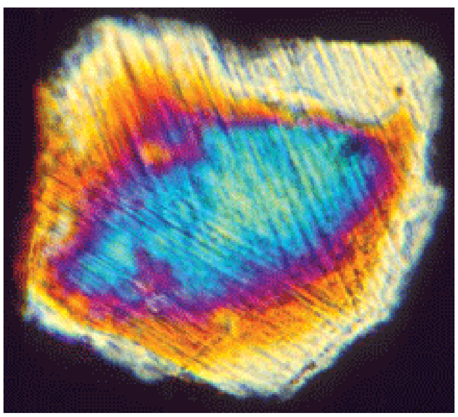

Figure EX.11 Polarized light accentuates parallel fractures along multiple directions in this grain of quartz, which was shocked when an extraterrestrial impact produced intense seismic vibrations. This sample was taken from 250 meters underneath NASA's Langley Research Center in Virginia, USA, which sits on the crater rim. Figure by Glen A. Izett, U.S. Geological Survey.

3d. Tsunami Deposits

Tsunami leave characteristic sedimentary deposits. These characteristic sedimentary features are found in Mexico, Texas, New Jersey, and the Carolinas suggesting the passage of an enormous wave, far larger than could have been produced by standard tectonic processes. Such a wave could have been generated if an impact had occurred in the ocean.

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4. The Chicxulub Impact Crater

All the evidence discussed previously supported the possibility of an impact at the end of the Cretaceous but the "smoking gun," the actual impact crater remained elusive. It was suggested that the crater could have been removed by a number of processes including erosion or even subduction if impact had occurred on oceanic crust.

However, the distribution of tektites, iridium, shocked quartz, and other potential impact related features was pointing towards a possible centre of activity in the Yucatan Peninsula of Mexico. An oil company had drilled wells in the area and encountered unusual fractured and even melted rock suggesting the area had been subjected to some form of extreme stress. The presence of a crater was finally confirmed when geophysical data revealed a large circular disturbance over 180 km in diameter, the **Chicxulub Impact Crater**.

Figure EX.12 (above) A buried impact crater is shown on the tip of the Yucatan Peninsula.
(right, top and bottom) Shaded relief of the Yucatan Peninsula, Mexico based on data from the Shuttle Radar Topography Mission. The top figure shows a subtle but unmistakable topographic indication of the outer boundaries of an impact crater. These boundaries are outlined in the lower figure.
Figures from University of California Museum of Paleontology (above) and NASA (right).

The object responsible for this crater had a shallow angle of entry around 20 – 30° and is estimated to have been at least 10 km across. As an analogy, you can think of something the size of Mount Everest hitting the surface of the planet. The energy released by the impact was equivalent to 6.2×10^7 tons of TNT. 100 km^3 of rock was vaporized and released to the atmosphere. Material that wasn't instantly vaporized was thrown out of the crater (the **ejecta**) and was deposited to the NW of the impact site.

5a. Consequences of the Chicxulub Impact: Initial Effects

Initial effects (seconds to days) of the impact in the area of the Yucatan Peninsula were significant.

i. Everything close by would have been vaporized.

ii. The intense heat from the blast and the hot debris (including tektites) would have started massive forest fires as suggested by the fern and pollen data.

iii. As the impact occurred partly in the ocean, a massive tsunami would have been generated.

5b. Longer-Term Effects: Global Temperature Changes

Longer-term (months to decades) effects of the impact were numerous. Two significant effects were on global temperature and on atmospheric composition.

i. Global Temperature Changes

a. Dust thrown into the atmosphere would have shut off sunlight for weeks or perhaps months generating a period of cold (a "**Cold House**"), lasting weeks to months. The lack of sunlight would also have had severe consequences for plants and photosynthetic algae.

b. After the dust had settled, water vapour would have remained in the atmosphere acting as a blanket, preventing heat from escaping the Earth. This would have created a greenhouse effect and caused a rise in global temperature.

c. Eventually the excess water vapour would be removed by rainfall. However, the temperature of the Earth would continue to rise due to the release of greenhouse gasses during impact (a "**Hot House**"), lasting years to decades. In particular, carbon dioxide would have been liberated when large quantities of limestone (calcium carbonate, $CaCO_3$) would have vaporized during the impact.

The Mesozoic had in general been a warm equable environment. These swings in temperature would have placed a lot of stress on creatures more used to stable climatic conditions.

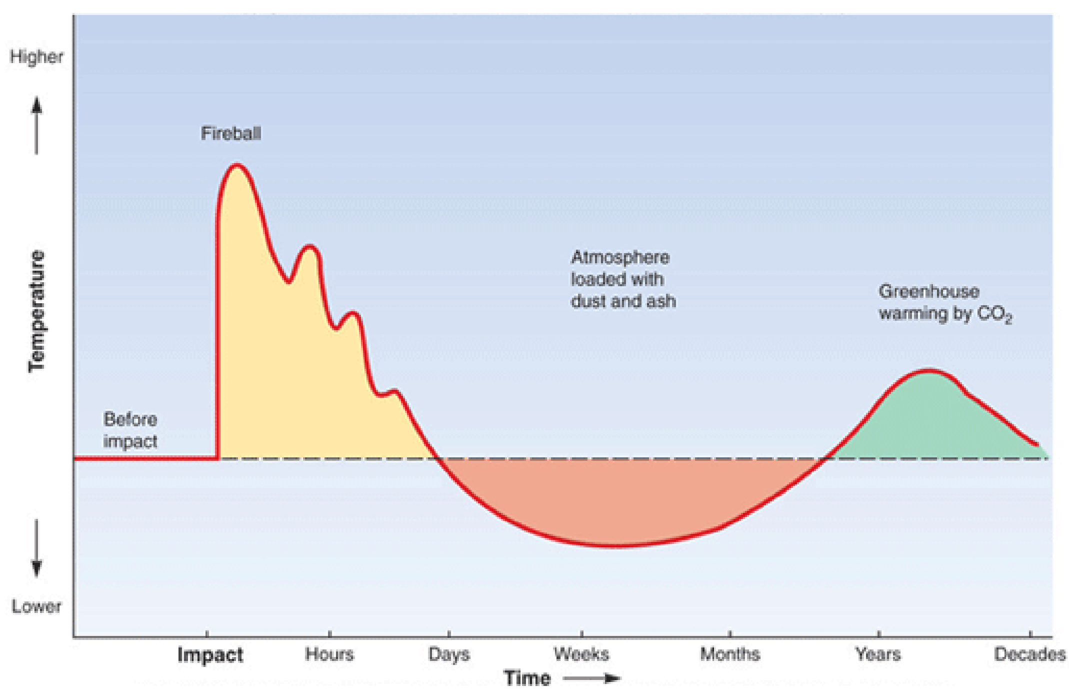

Figure EX.13 A plot describing the marked effects of the impact of the K/Pg asteroid on Earth's surface temperatures.

ii. Acid Rain

a. High-energy blasts can cause oxygen to combine with nitrogen to form **oxides of nitrogen**. When these are dissolved in water (i.e., rainfall), it becomes **nitric acid**.

b. In addition to the vaporization of limestone as described above, rocks called **evaporites** were also vaporized in the blast.

   Evaporites form when salts precipitate out of solution as the sun evaporates a body of water. This can occur on a vast scale, for example in the Mediterranean, where the Sea is closed off at the Strait of Gibraltar. With virtually no input of water from the Atlantic Ocean, high rates of evaporation resulted in the Sea being converted into a vast saltpan. This process had also occurred in the Yucatan area.

   The effect of high-energy blasts on sulfate-rich evaporites is the release of large amounts of sulfur gases. These gases, when dissolved in rainwater, fall to Earth as **sulfuric acid**.

   Although the acidity of the nitric- and sulfuric-containing rain was weak and could probably not affect any large animals directly, they would have affected the acidity of soil and the surface ocean. This would have had a devastating effect on plant life and plankton. Thus, the effects from acid rain on the organisms that form the **base of the food chain or food web** had serious repercussions for all the creatures at higher trophic levels. For reference on how a food chain/food web operates, see a modern example below.

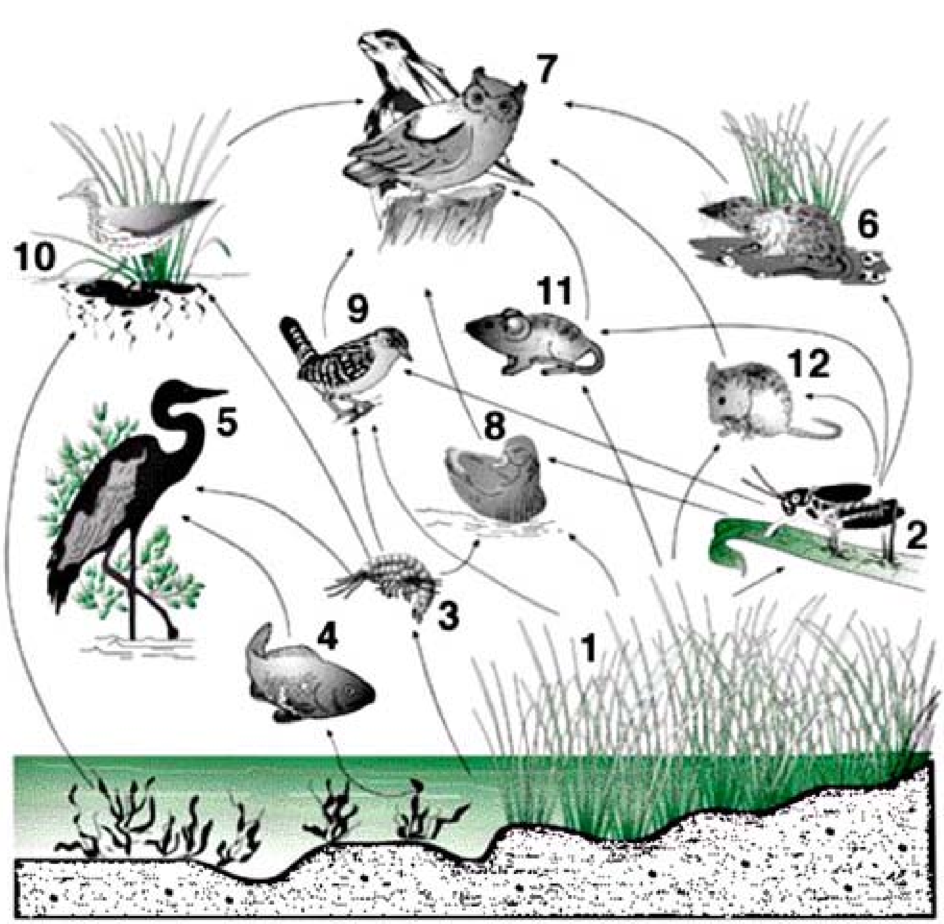

Figure EX.14 Illustration of a food web in a modern-day salt marsh. Note how every creature in this food chain / food web ultimately relies on those creatures at the base of the scheme.

CHECK YOUR UNDERSTANDING:

Which of the following may have been responsible for the acidification of oceans and land surfaces following the Chicxulub Impact at the end of the Cretaceous?
A) formation of oxides of nitrogen
b) vaporization of limestone
C) vaporization of ejecta
D) tsunami
E) death of non-avian dinosaurs

---

6. Is Impact the Only Cause of the K/Pg Extinction?

Scientists remain convinced that an impact at the K/Pg boundary (perhaps not at Chicxulub) was a major cause of the mass extinction event 65 million years ago. This impact would have been significantly larger than the Chicxulub impact.

However, an impact would NOT have been the only cause. The K/Pg extinction was probably the result of many factors.

- During the late Cretaceous, the supercontinent of Pangaea was starting to fragment. This would have caused changes in oceanic circulation and climate.
- Even more significantly, global climate would have been affected by an increase in volcanic activity, in particular, during the formation of the Deccan Traps in India, which were highly active at this time. Like the Siberian Traps that occurred at the end of the Permian, this activity would have produced vast quantities of gasses that could have seriously affected the Earth's climate.

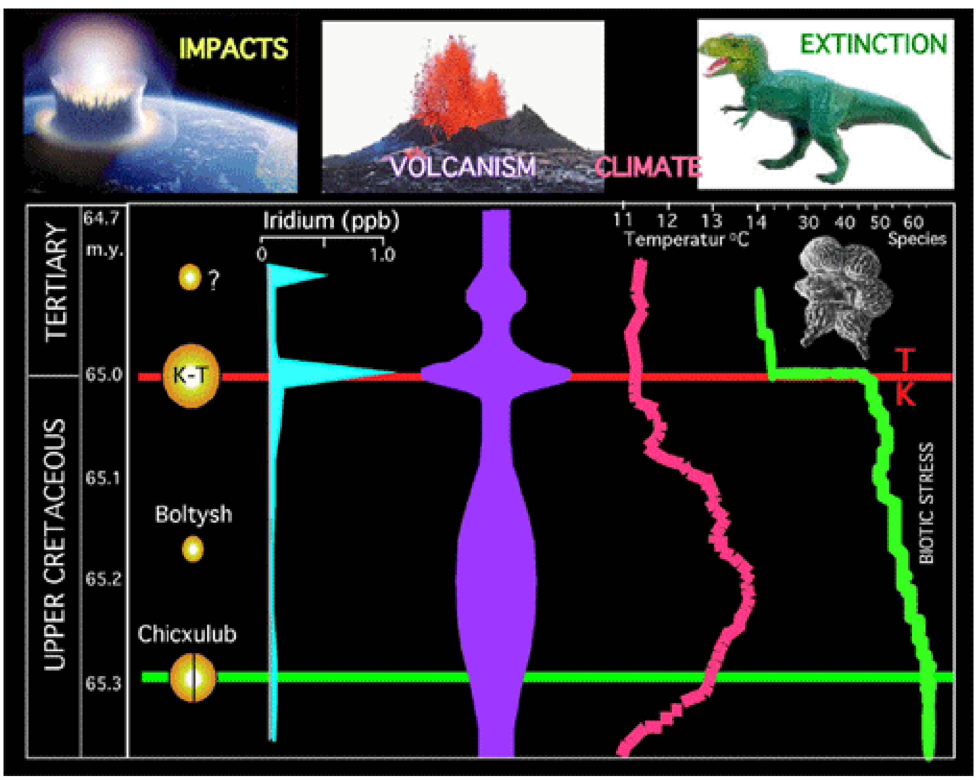

Figure EX.15 A plot summarizing the events that led to the K/Pg mass extinction, including multiple impacts, volcanism, and global climate change. (Tertiary=former term for Paleogene) Figure from The Chicxulub Debate.

CHECK YOUR UNDERSTANDING:

Consider this statement:
"The Siberian Traps was an area of intense basaltic volcanic activity at the end of the Cretaceous, and is thought to have had serious consequences for the health of the biosphere."
Which of the following is the MOST APPROPRIATE response to the statement above?
A) The statement would be true if the volcanic activity referred to was that in the Deccan area of India NOT in Siberia.
B) The statement is NOT true because the Chicxulub impact was entirely responsible for the extinction event at the end of the Cretaceous.
C) The statement is accurate.
D) The statement is UNTRUE because there is no recorded volcanic activity at the end of the Cretaceous.
E) The statement would be true if it referred to the End Ordovician and NOT the K/Pg extinction.

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7. The K/Pg Survivors

In conclusion, the late Cretaceous biosphere was probably already stressed. The Chicxulub impact acted as the "final nail in the coffin" taking an already "sick" biosphere further than it might have gone into a mass extinction event.

The creatures most likely to survive all the changes in environmental conditions would have been the **generalists** who did not require specific foodstuffs or particular environments to thrive. It would also help if a creature were small enough to be able to hide or burrow away from the more severe environmental changes. On land, the creatures that were able to adapt to these changes were the **mammals**. And it is this group that will radiate into the Cenozoic to take over the niches vacated by the dinosaurs.

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8. Glossary of Terms/People

Alvarez, W and A
: father and son team who investigated the iridium anomaly

ammonite
: extinct group of marine creatures related to squid and octopus

avian/aves
: birds

breccia
: fractured rocks

Cold House
: globally cold climatic conditions

crater (impact)
: any depression in the ground resulting from a high velocity impact

dinosaurs
: a group of vertebrates common during the Mesozoic

ejecta
: material ejected from a crater during an impact

evaporites
: rocks produced by the evaporation of standing bodies of water

food chain
: feeding relationships between organisms in an ecosystem

geophysics
: the physics of geology; commonly used to study subsurface features

gravity survey

studying variations in Earth's gravity to reveal subsurface features

gypsum
: a mineral rich in sulfates; common in evaporite sequences

Hot House
: globally warm climatic conditions

iridium
: a rare Earth element

limestone
: a rock composed of calcium carbonate

microplankton
: tiny creatures floating in the water column; often the base of oceanic food chains

nuclear winter
: cold period after a nuclear war caused by dust/soot/smoke in atmosphere

ozone
: tri-oxygen molecule; ozone layer filters harmful UV

photosynthesis
: process by which plants use light to convert CO_2 into organic compounds

pollen
: the reproductive structure in flowering plants adapted for dispersal

shock lamellae
: stress lines in quartz crystals generated by high energy events

shocked quartz
: quartz deformed along planes called shock lamellae

spores
: a reproductive structure adapted for dispersal

suevite
: partially melted fractured rock

tektites
: natural glass produced by melting rocks during an impact event

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UNIT	TOPIC
C	Impacts and Mankind

Outline

1. Sources of Extraterrestrial Debris that could Impact Earth
    - Comets
    - Asteroids
2. Rates of Meteoroid Influx
3. History of Impacts
4. Periodicity of Mass Extinctions
    - Nemesis - Companion Star
    - Planet X
    - Movement Through the Galactic Plane

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1. Sources of Extraterrestrial Debris that Could Impact Earth

Impacts from space have the potential to be the most devastating natural disaster that humans could face. We examine here the likelihood of impacts, the effect impacts may have, and the strategies we could use to avoid such a disaster.

1a. Comets

Comets are essentially material left over from the formation of the solar system and are composed of icy material and other debris - effectively "dirty snowballs" in space. As comets travel towards the Sun, the ices vaporize producing the comet's tail.

Two examples of comets are comet **Halley**, which comes into view of the Earth every 74 - 79 years and comet **Hale-Bopp** that was last seen in the night sky in 1997 and will return in 2,380 years. An annual event is the **Leonid Meteor Shower**, which is visible in Canadian skies in November. This rain of "shooting stars" is produced as the Earth passes through the debris left behind by comet **Temple-Tuttle** as it orbits around the Sun.

There are two comet "stores"in the solar system (see figure below).

i. **The Kuiper belt** exists in an area from about the orbit of Neptune to about 50 au's out (1 au = 150 million kilometres).
ii. **The Oort cloud** is a cloud of comets that exists way beyond the Kuiper belt and is only weakly associated with our Sun.

The Kuiper belt may contain 1 billion (1 000 000 000 = 1×10^9) comets that are greater than 5 km in diameter. The Oort cloud may have more than 200 comets with a diameter greater than 500 km with many smaller but still significant in size. It is interesting to note that comets may have been responsible for bringing much of the water and perhaps some of the organic compounds that would lead to the development of life on Earth.

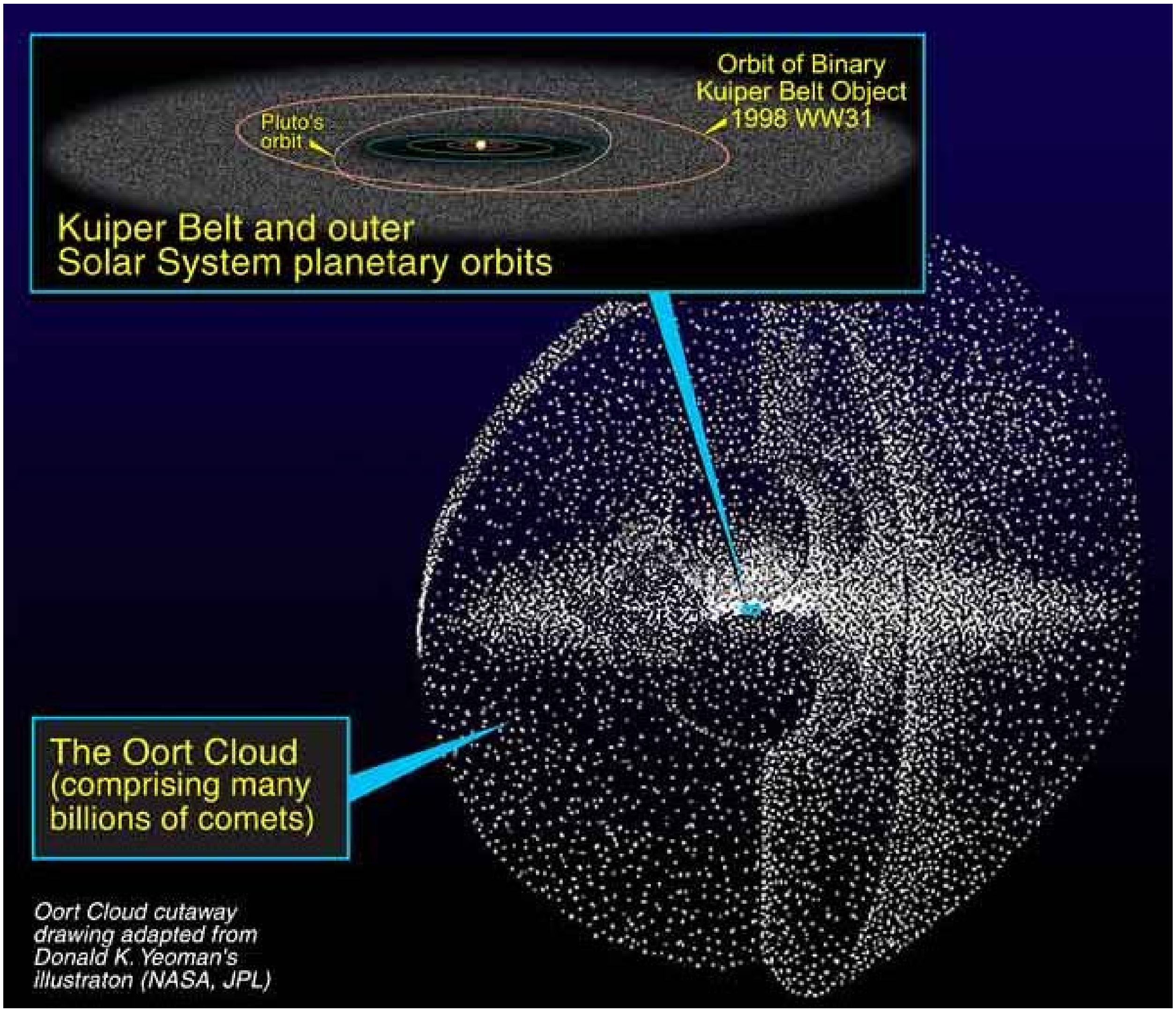
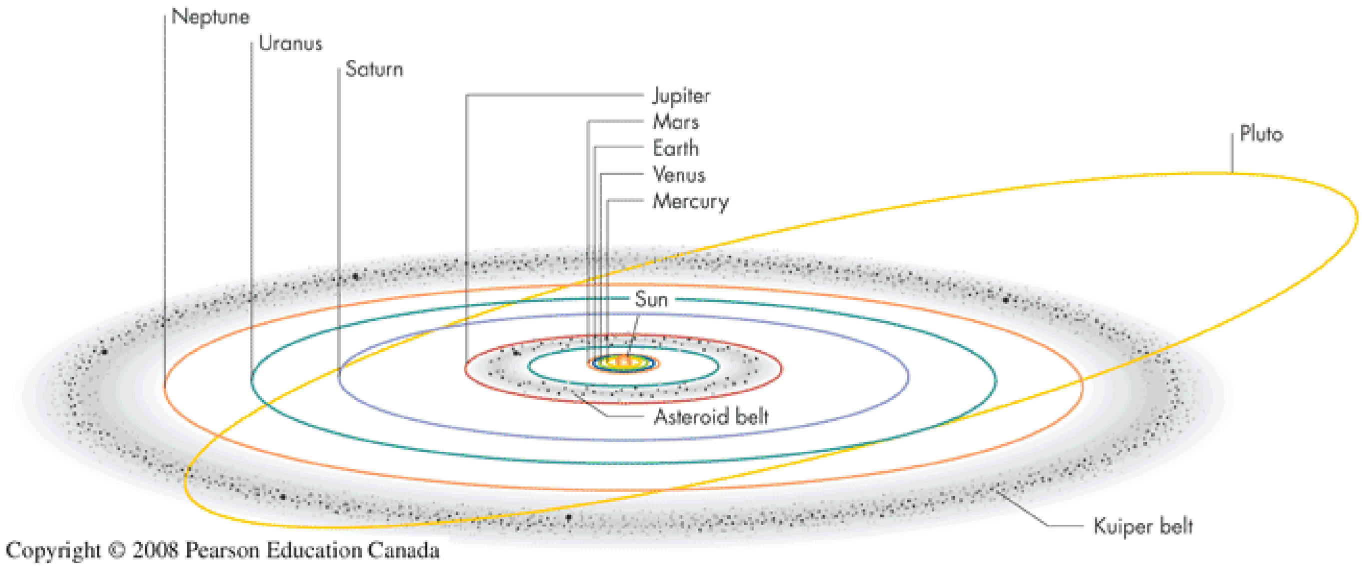


Figure EX.16 The Kuiper Belt and Oort Cloud. Drawing adapted from Donald K. Yeoman's (NASA-JPL) illustration.

1b. Asteroids

Asteroids are mostly found in a belt between the orbit of Mars and Jupiter. It is speculate that they may represent the material that might have formed another planet early in the history of the Solar System if it were not for the gravitational effects of Jupiter.

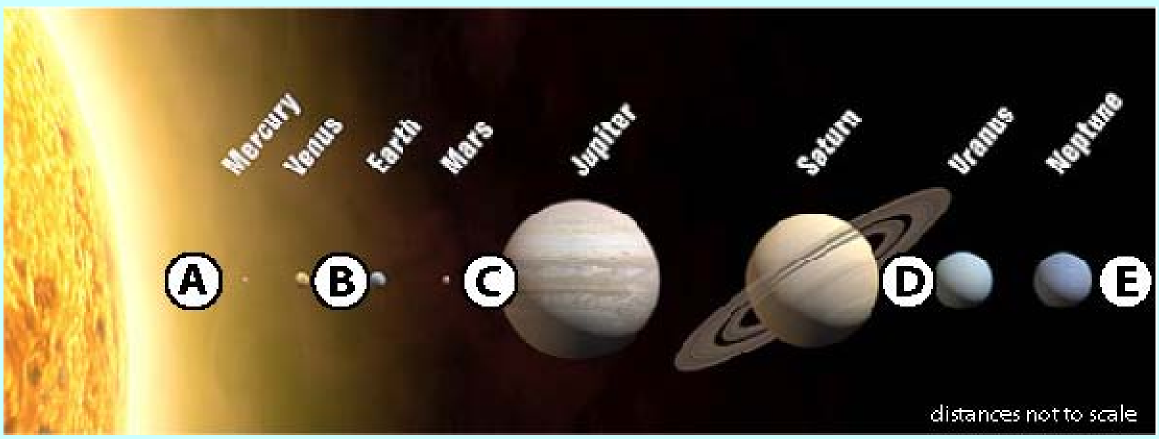
Some asteroids are solid, rocky to metallic while others are little more than "rubble piles" in space. Collisions between asteroids could potentially cause them to be redirected into Earth crossing orbits. Of those so far mapped, a few are over 500 km in diameter, about 1000 have diameters greater than 30 km and 1 million (1 000 000 = 1×10^6) with diameters over 1 km.



Solar System. A diagram of our planetary system showing the asteroid and Kuiper belts. Orbits of the planets and belts are not to scale. Figure from *Keller et al., 2011*.

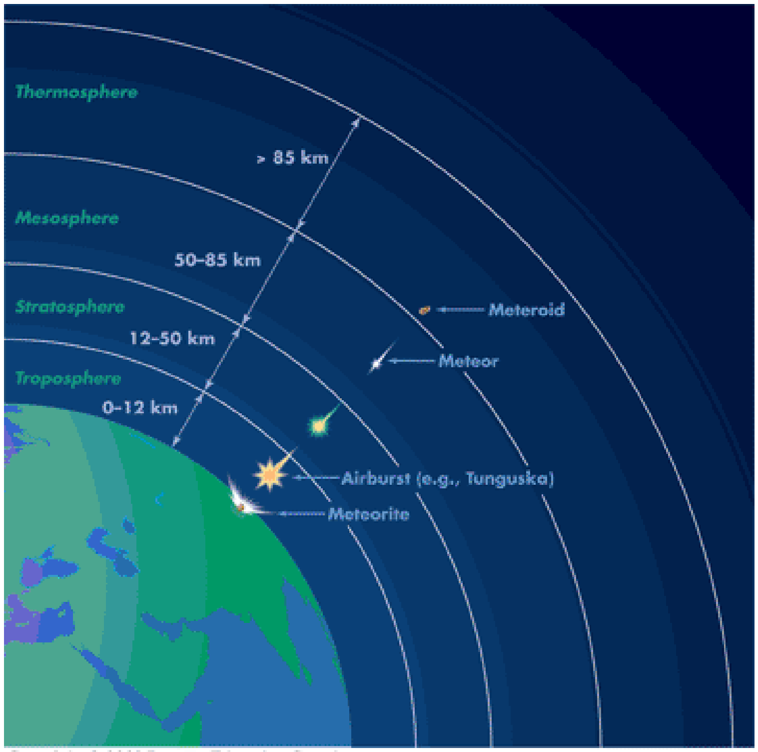
CHECK YOUR UNDERSTANDING:

At which location would you expect to find the majority of asteroids in our Solar System?



2. Rates of Meteoroid Influx

Around 100 billion (100 000 000 000 = 1 x 10^{11}) objects enter our atmosphere every 24 hours! Most of these burn up 60 km above the surface. These objects are commonly traveling around 11 - 30 km / second. At such speeds, the atmosphere acts like a brick wall. If an object enters at a shallow angle, it may skip like a stone being skipped across a pond and fly back out to space.

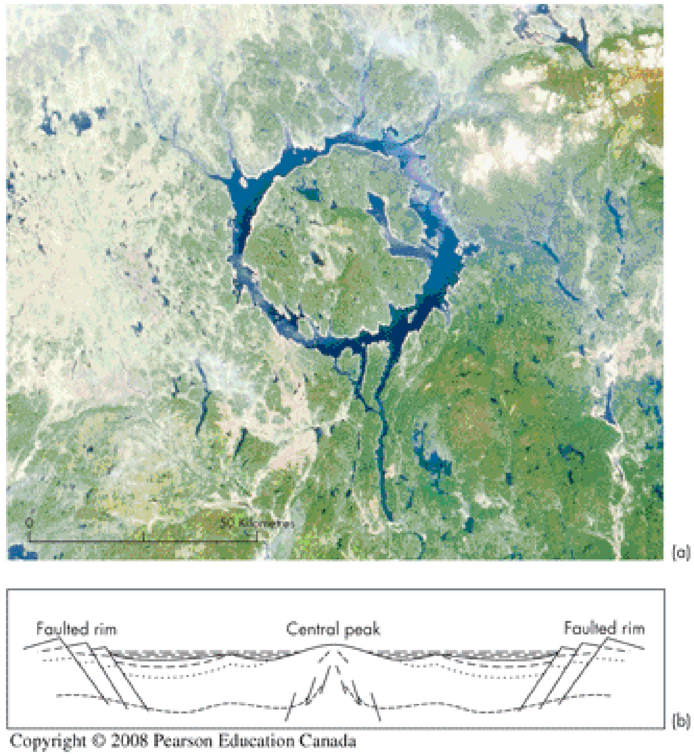


The fate of a meteoroid in Earth's atmosphere. An idealized diagram showing what happens to a meteoroid when it enters Earth's atmosphere. Meteors are small sand- to dust-sized meteoroids that emit light in the mesosphere and stratosphere. A large meteoroid may break apart in an aerial burst or crash into Earth. Figure from *Keller et al., 2011*.

3. History of Impacts

Early in Earth's history, our planet probably suffered multiple impacts. We can see this by observing the craters on the moon and some on our neighbours' like Mercury. The evidence of this early bombardment is missing on Earth due to processes of erosion and active plate tectonics. Until recently (1960's) the possibility of impact on Earth's surface was regarded as improbable. Craters such as Meteor Crater in Arizona and even the craters on the moon were held by some to represent extinct volcanoes and not impact craters at all.

Gene Shoemaker was to change this view by studying features such as the material thrown out of a crater (ejecta), shocked quartz, and chemical anomalies, which demonstrated extraterrestrial origins for these features. With the aid of satellite imagery, we are now beginning to identify more craters on the surface of our planet. A significant impact crater can be found in Northern Quebec, the **Manicouagan impact crater**. This formed about 214 million years ago in the Late Triassic. It is 70 km in diameter but was probably as wide as 100 km before glacial erosion stripped away the upper levels.



Complex impact crater in Quebec. (a) Satellite image and (b) cross-section of the Manicouagan impact structure northeast of Quebec City. Figure from *Keller et al., 2011*.

This impact event is thought to be associated with 4 others including the **Saint Martin Crater** in Manitoba (40 km in diameter) and the **Rouchechouart Crater** in France (25 km in diameter). When the continents are reassembled into their locations during the late Triassic all these craters line up along 22.8 °N latitude over 462 km. It is thought that this may represent a fragmented body that generated several impacts. It is interesting to note that although the effects of this impact would have been severe it is not associated with a major mass extinction event.

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4. Periodicity of Mass Extinctions

Now that we have established that impacts have occurred on the surface of our planet it would be wise to see if there is a predictable frequency of those impacts. Two researchers, Raup and Sepkoski, produced some worrying data in 1984. They analyzed the number of mass extinctions during the Phanerozoic and concluded that every 25 million years there was severe stress in the biosphere, sometimes associated with a mass extinction event.

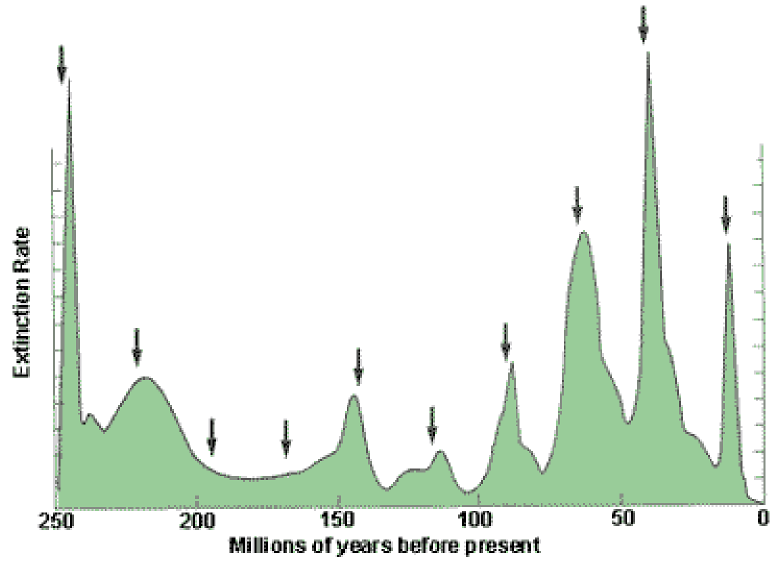


Figure EX.17 A plot of data on life extinctions, collected by D. Raup and J.J. Sepkoski at the University of Chicago shows peaks in the extinction rate occurring at 26- to 30-million year intervals as indicated by the arrows. Figure from Raup, D. and J.J. Sepkoski, 1984 ("Periodicities of extinctions in the geologic past", *Proceedings of the National Academy of Science*, 81:801-805).

There is no known terrestrial geological process that could cause this frequency of problems for the biosphere so it was suggested that an extraterrestrial source may be to blame. In particular, comets in the Oort cloud were cited as being the most likely culprit. The hypothesis suggests that every 25 - 26 million years, something shifts the Oort cloud, which causes some comets to fall in towards the Sun and a possible impact with the Earth. For this to work, we need to identify a gravity source that can cause disturbances in the cloud on a regular 25-million year basis. The hypotheses proposed to account for this periodicity will be discussed in the next pages.

CHECK YOUR UNDERSTANDING:

The periodicity in extinctions proposed by Raup and Sepkoski is thought to be related to ______.
A) asteroids
B) glaciations
C) sea level change
D) meteoroids
E) comets

4a. Nemesis - Companion Star

This hypothesis proposes that our Sun has a **companion star** way beyond the outer limits of our Solar System whose orbit brings it close to the Oort cloud every 25 million years. The gravitational effects of this close pass could cause comets to fall into the inner Solar System. If this body was a red dwarf star or even a black hole, it might be difficult to detect. However, even though powerful telescopes such as Hubble have the ability to see such faint objects, none have been found.

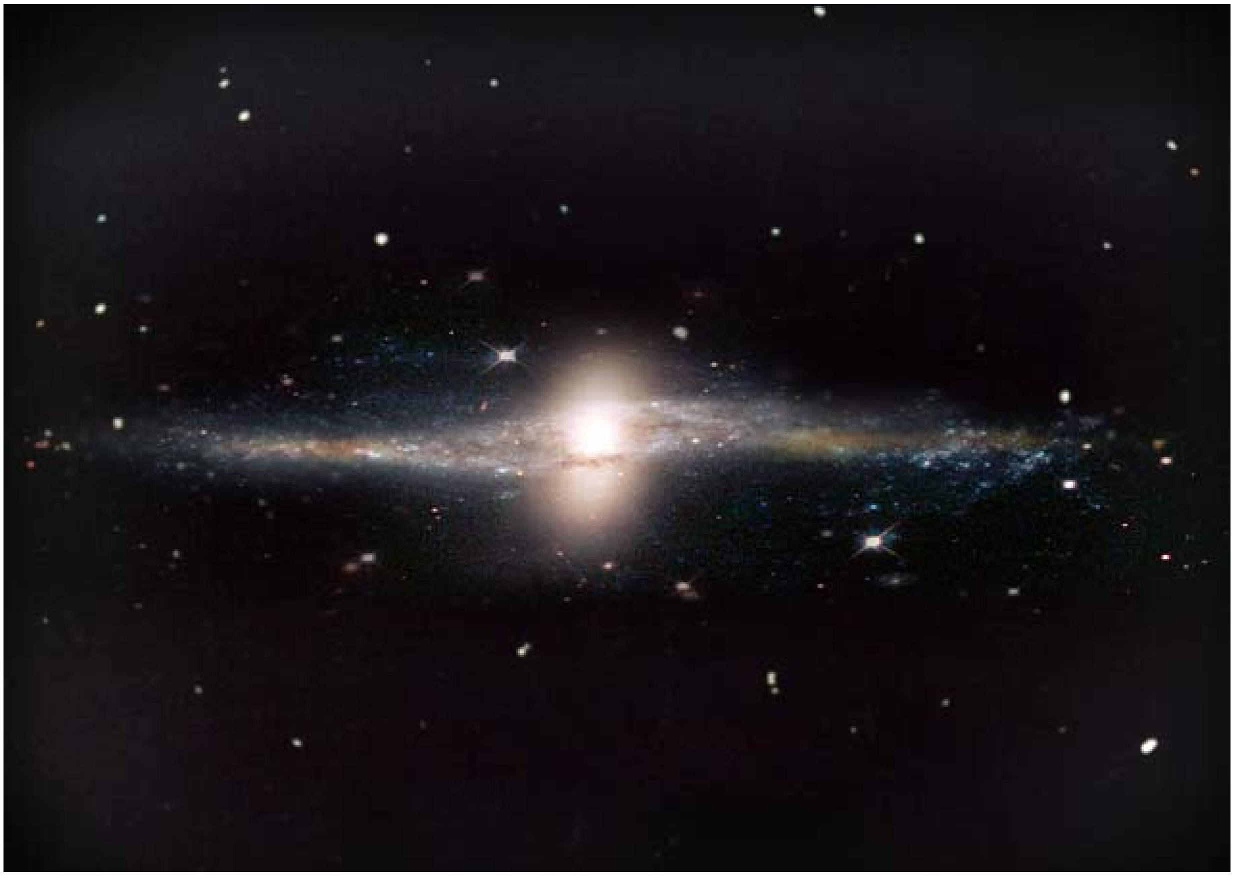
4b. Planet X

Like the Nemesis hypothesis, this has an astronomical body (**Planet X**) that causes shifts in the Oort cloud as it orbits around the Sun. In this case, the body is a planet lying within the bounds of the Oort cloud but outside the Kuiper belt. Again, no evidence of such a planet has been found.

4c. Movement Through the Galactic Plane

In the same way that our planet orbits the Sun, so our Solar System orbits around the centre of the Milky Wa Galaxy. The figure below shows the position of our Solar System in one of the spiral arms of the galaxy. However, galaxies are not just flat pancakes of stars, they also have "thickness".

In addition to traveling around our galaxy, our solar system is also moving up and down through it. Every 25 - 26 million years we pass through the densest part of the galaxy, which contains a higher number of stars and also the most gravitational effects. It is proposed that it is this movement through the dense part of the galactic plane that is responsible for the shifts in the Oort cloud and thereby a potential impact related biosphere crisis every 25 million years or so.



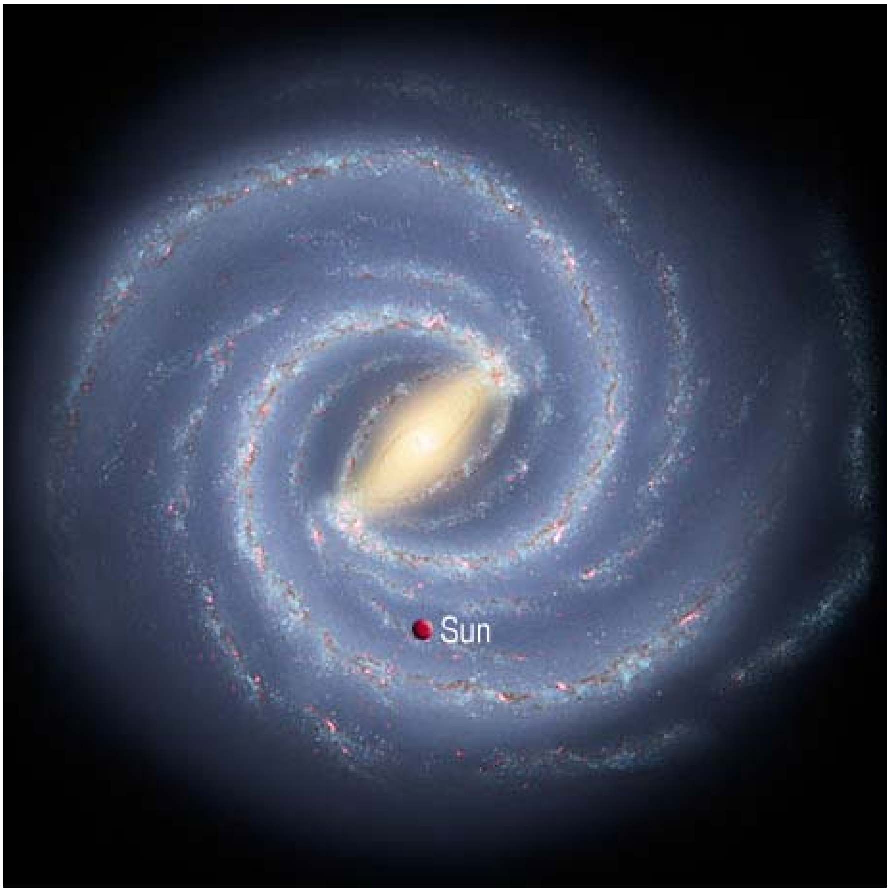


Figure EX.18 (above) An edge-on view of our Milky Way galaxy in infrared light, as captured by the Goddard Space Flight Center's Cosmic Background Explorer (COBE) from its orbit around Earth. Image downloaded from NASA.
(left) Artist's rendition of the Milky Way Galaxy if viewed from above. Note the location of our Sun. Illustration by R. Hurt, as published by NASA-JPL-Caltech.

We just passed through the densest part of the galaxy about a million years ago. However, it takes about 1 million years for comets from the Oort cloud to reach the inner Solar System. If Raup and Sepkoski are correct that could mean we are due for an increased probability of impact from comets. This hypothesis is still highly controversial. Many scientists have criticized the data stating that the spacing between the "biosphere crises" is not always consistent. They have also been critical of the statistics that Raup and Sepkoski used in identifying the extinction events.

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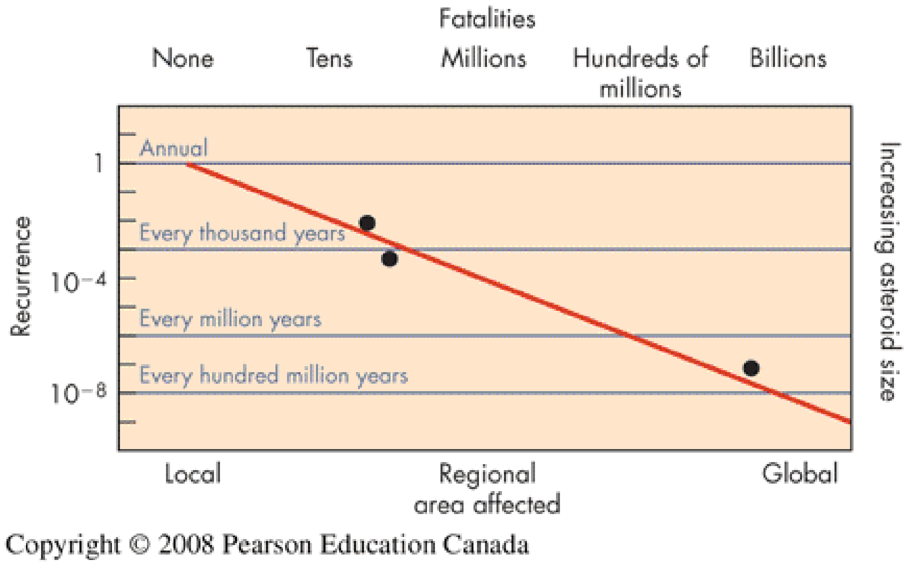
5. Just How Safe Are We?

Even if we do not have an impact on the scale of the K/Pg event, an impact from space could still cause great problems for society. With cities spreading across the globe, there is now a greater chance of a built-up area being affected by impact from space.

The periodicity of a potential "city killer" impact is random but statistically could occur around once every million years. The risk of being killed in an impact event by a body around 1 km or greater in the next 50 years is about 1:20,000. This is the same level risk of being killed in an air crash! These numbers are similar due to the way risks are calculated. Both the frequency of the event and the potential number of deaths are a factor. For an air crash, the frequency is high but the number of deaths is low while for an impact event, frequency is relatively low but deaths potentially very high.

We can pose the risk data in a similar light, plotting recurrence interval, which is inversely proportional to asteroid size, and number of fatalities, which is correlated to the size of the affected area.



Asteroid risk. Graph showing fatalities and areas affected by asteroid impacts with different recurrence intervals. Small impacts that occur annually are at little risk. An impact with an average recurrence interval of 100 million years would kill billions of people. Figure from *Keller et al., 2011*.

CHECK YOUR UNDERSTANDING:

What is the potential risk of you being killed by an impact event?
A) 1: 200
B) 1: 2,000
C) 1: 20,000
D) 1: 200,000
E) 1: 2,000,000

How does this compare with your risk of being killed by a car crash? an airplane crash? an earthquake?

---

6. Recent History of Impacts

In order to fully understand the risks, we need to consider impacts or near misses that have occurred recently. In the following pages, we will discuss specific events, hits and near-misses.

6a. Tunguska, Siberia: June 30, 1908

A large explosion about 8 km above the surface attributed to an extraterrestrial object breaking up in the atmosphere (which is why no crater was found). Fortunately, the area was not populated but people and horses 480 km away were knocked off their feet. The shockwave from the blast traveled around the Earth twice. In Scotland and Sweden, a light appeared in the sky so bright that you could read books at 2 AM without the aid of artificial light. It has been suggested that this might have been a fragment of comet Encke which was passing close by the Earth at the time.

Over 80 million trees were knocked over covering an area about 2,150 km^2. To properly understand the damage that could have occurred to a modern city, compare the area of the Tunguska devastation to that of the area occupied by Washington, D.C. in (figure below).

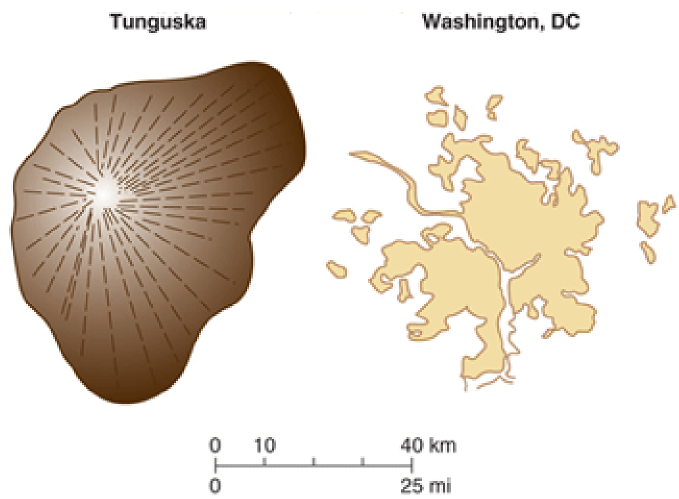


Figure EX.19 The Tunguska event in 1908 devastated more than 2,150 km^2, knocking down most trees. Had this comet exploded over Washington, D.C., it would have been one of the major events in history.

6b. Asteroid near misses: 1989, 1996, 2009, 2011

March 22, 1989: A 500-m asteroid misses Earth by 6 hours. The impact crater would have been 7 km across.

May 19, 1996: A 150-m diameter asteroid misses Earth by 430 000 km, a hairs-breadth away in astronomical terms. The Crater would have been around 1 km in diameter (similar to Meteor Crater in the USA) and released twice the energy produced by Mount St. Helens in 1980.

March 2, 2009, 5:44 AM Pacific Time (were you asleep?): Asteroid 2009 DD45, 40 m in diameter, buzzed about 70 000 km from Earth, about 1/5 of the distance between the Earth and the moon. The asteroid's size is comparable to that of the Tunguska impactor of 1908.

November 7, 2011, 3:28 PM Pacific Time (point of closest approach): Asteroid 2005 YU55, a 70-metre wide asteroid was as close as 324,900 km (from the centre of the Earth). Scientists used this flyby as an opportunity to make observations of the asteroid's surface.

6c. Comet Shoemaker Levy 9 Impact with Jupiter in 1994

Not exactly close but still in the neighbourhood, was the impact of comet Shoemaker Levy 9 with Jupiter. The comet had been fragmented by Jupiter's strong gravity and crashed into the giant planet in a series of explosions between 16 - 22 July, 1994.

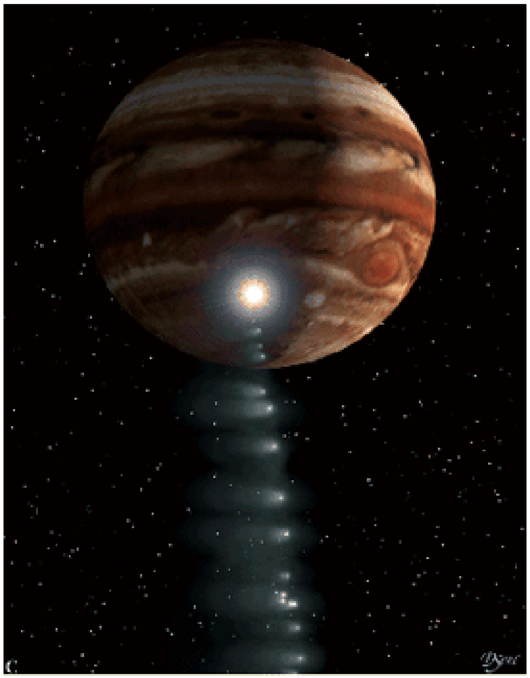


Figure EX.20 A fragmented Comet Shoemaker Levy 9 impacts Jupiter. Image from NASA-JPL.

This series of impacts was equivalent to several million megatons of TNT, enough energy to wipe out all but the simplest forms of life if the impact had occurred on Earth. It is thought that the **presence of Jupiter and our very large moon** has been significant in protecting the Earth from more frequent major impacts. It is probably these "impact shields" taking some of the hits Earth might have suffered that have permitted our biosphere to become as complex and diverse as it is today.

CHECK YOUR UNDERSTANDING:

The Tunguska event is notable in that it ______.
A) produced a crater 180 km across
B) was responsible for the extinction of many Siberian species
C) is associated with other impact craters in France and Canada
D) left no impact crater
E) caused a large tsunami in the Black Sea

7. What Is Being Done? (A Defense Plan)

The most important factor in preventing an impact on Earth is **time**. We need time to know which objects are a potential risk. Then we need **lots of time** to make appropriate plans and to build what we need for our defense. The Spaceguard Survey at NASA has analyzed space objects with diameters greater than 1 km. 90% of potential impactors are near-Earth asteroids or short period comets with another 10% being intermediate or long period comets (greater than 200-year return periods). Go to this NASA website to read more about Spaceguard.

The recent very close flyby by Asteroid 2005 YU55 is a very good example of what we're faced with in terms of threats of impacts from near Earth objects. This asteroid and its trajectory came to NASA's attention in 2005. Had it been on a direct course towards Earth, we would only have 6 years to diffuse the threat. Click here to visit NASA's Asteroid and Comet Watch to read more about Asteroid 2005 YU55.

A threat scale is commonly used to assess the risk of near-Earth objects (NEO's). This **Torino Scale** communicates potential threat on a scale of 0 - 10.

THE TORINO IMPACT HAZARD SCALE

Assessing Asteroid And Comet Impact Hazard Predictions In The 21st Century

No Hazard (White Zone)	0	The likelihood of a collision is zero, or is so low as to be effectively zero. Also applies to small objects such as meteors and bodies that burn up in the atmosphere as well as infrequent meteorite falls that rarely cause damage.
Normal (Green Zone)	1	A routine discovery in which a pass near Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to re-assignment to Level 0.
Meriting Attention by Astronomers (Yellow Zone)	2	A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely will lead to re-assignment to Level 0.
	3	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away.
	4	A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by public and by public officials is merited if the encounter is less than a decade away.
Threatening (Orange Zone)	5	A close encounter posing a serious, but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.
	6	A close encounter by a large object posing a serious but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted.
	7	A very close encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur.
Certain Collisions (Red Zone)	8	A collision is certain, capable of causing localized destruction for an impact over land or possibly a tsunami if close offshore. Such events occur on average between once per 50 years and once per several 1000 years.
	9	A collision is certain, capable of causing unprecedented regional devastation for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once per 100,000 years.
	10	A collision is certain, capable of causing global climatic catastrophe that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

Table downloaded from NASA-JPL. Note: the Torino Scale was recently revised by Morrison, D. et al., 2004 ("Impacts and the Public: Communicating the Nature of the Impact Hazard" In *Mitigation of Hazardous Comets and Asteroids*, M.J.S. Belton, T.H. Morgan, N.H. Samarasinha and D.K. Yeomans, Eds., Cambridge University Press)

8. Proposed Impact Mitigation Strategies

The impact hazard is unique. It is potentially the most devastating but the **only** disaster that can be completely avoided. The most important factor in all the following strategies is **time**. We need to have a long warning period of potential impact, which makes projects like Spaceguard vital. Below are selected impact mitigation strategies that have been proposed.

1. **Fragmentation.** Destroy an approaching impactor with nuclear weapons. This might not work for metallic bodies, as we may have to drill into an object to deploy the weapon, which would be difficult. Even if fragmentation was achieved there is no guarantee that the fragments produced during the explosion would not still impact our planet.

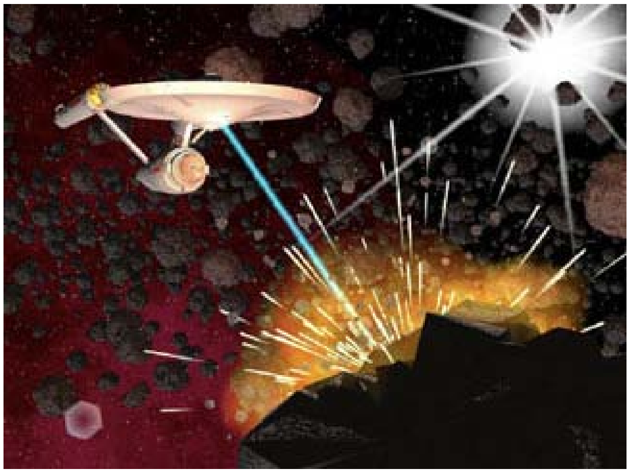
2. **Sudden Orbit Adjustment.** This would involve exploding a nuclear warhead in front or on the surface of an approaching body to adjust its trajectory so it is no longer an impact threat. Such a solution is still rather unpredictable.

3. **Steady State Orbit Adjustment.** These strategies would require more warning time but would permit adjustment of the orbit of the approaching object in a more predictable manner.

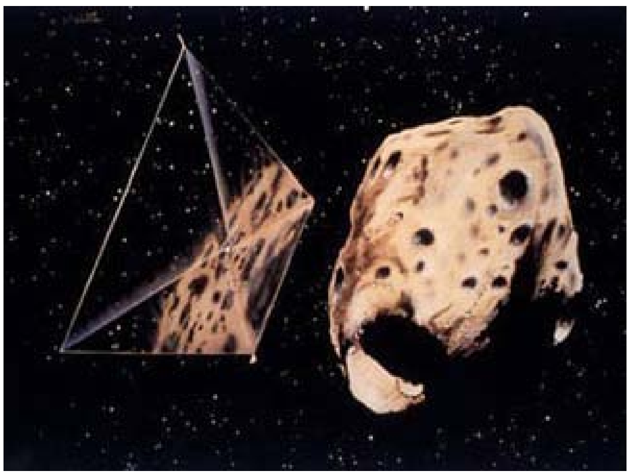
   a. Attach chemical or nuclear rocks to the object to gently nudge it out of the way.

   b. Land robot "mass drivers" on the surface of the object. These would excavate material and launch it off the surface. This action would act as a form of propulsion and slowly change the approaching object's trajectory.

   c. Ablation systems: irradiate the surface with lasers or focus sunlight with large mirrors. The gases produced by vapourizing the surface would act as a propellant to adjust the object's trajectory.



d. Attached large solar sails. These are large reflective mirrors that "catch" charged particles from the Sun (solar wind) and act like giant sails in space.



Continual vigilance and the development of some of these strategies will cost many tax dollars. As citizens, we have to assess the potential risk from impacts in the light of other pressing issues such as climate change, disease, and poverty. Remember, extraterrestrial impacts have **low** frequency but extremely **high** cost to society when they occur.

CHECK YOUR UNDERSTANDING:

What is the MOST important factor in preventing a possible impact on Earth?
A) knowing the composition of the asteroid or comet
B) having enough warning time
C) knowing the speed of the impactor
D) knowing the possible angle of impact
E) knowing the possible location of the impact

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9. Glossary of Terms/People

ablation
: removal of material from the surface of an object by vapourization

air burst

a detonation in the atmosphere

asteroid

a Solar System body larger than a meteoroid, but smaller than a planet; does not have a tail

black hole

a region of space with an extremely powerful gravitational field

comet

a small Solar System body that exhibits a "tail' as it passes close to the Sun

galactic plane

the area of the galaxy that is most densely packed with stars

galaxy

a massive gravitationally-bound collection of stars and other matter

gravity well

gravitation field produced by a large body; other space bodies or objects can "fall' into this well

impactor

anything from outer space that might impact Earth's surface

Kuiper Belt

a ring of small Solar System objects including comets

mass driver

process of removing material off a large space body to cause the body to move

meteorite

object from space that survives impact with Earth's surface

meteoroid/meteor

objects in space that range in size from sand to large boulder; does not have a tail

Near-Earth Object (NEO)

any Solar System object in an orbit that passes close to Earth

Nemesis

a hypothetical companion star or black hole to our Sun

Oort Cloud

a spherical cloud of comets that surrounds the Sun at about 1 light year distance

Planet X

a hypothetic planet proposed to exist way beyond the orbit of Pluto

Raup, D. and Sepkoski, J.

two scientists who proposed that extinctions occur periodically, every 26-30 million years

Red Dwarf Star

a star smaller and cooler than our Sun

Shoemaker, Gene

a founder of planetary science; correctly deduced the nature of craters

solar sails

large mirrors designed to be installed in space to move/steer space bodies using energy from light (photons)

Solar System

the Sun and all the other celestial objects gravitationally bound to it

Spaceguard Survey

an international plan to survey all NEO's

Torino Scale

scale/method for categorizing impact hazards