Geologic Time Scale

- Early in the nineteenth century, geologists began to apply Steno's and Smith's lithostratigraphic and biostratigraphic principles to outcrops all over the world. They discovered the same distinctive fossils in similar formations at many locations. Many of the faunal successions from different continents displayed the same changes in fossil assemblages. By matching up faunal successions and using cross-cutting relationships, geologists were able to determine the relative ages of formations and establish a global geologic time scale for the Phanerozoic Eon, the most recent 542 million years of Earth history.

- The geologic time scale divides Earth's history into intervals characterized by fossil assemblages, and it places the boundaries of those intervals at times when those assemblages changed abruptly.

Geologic Time Scale Divisions

- The main subdivisions of the Phanerozoic Eon are the eras, the Paleozoic, the Mesozoic, and the Cenozoic eras. Each era is further subdivided into periods, usually named for the locality from which the formations representing them were first described, or for some distinguishing characteristic of the formations. Most of the periods are further subdivided into epochs.

Eon	Era	Period		Epoch	m.y.
Phanerozoic	Cenozoic	Quaternary		Holocene	
				Pleistocene	1.5
		Neogene		Pliocene	
				Miocene	23
		Paleogene		Oligocene	
				Eocene	
				Paleocene	65
	Mesozoic	Cretaceous			
		Jurassic			
		Triassic			250
	Paleozoic	Permian			
		Carboniferous	Pennsylvanian		
			Mississippian		
		Devonian			
		Silurian			
		Ordovician			
		Cambrian			540

Interval Boundaries Mark Mass Extinctions

- Many of the major boundaries indicate periods of mass extinctions, short time intervals during which a large proportion of species living at the time became extinct.

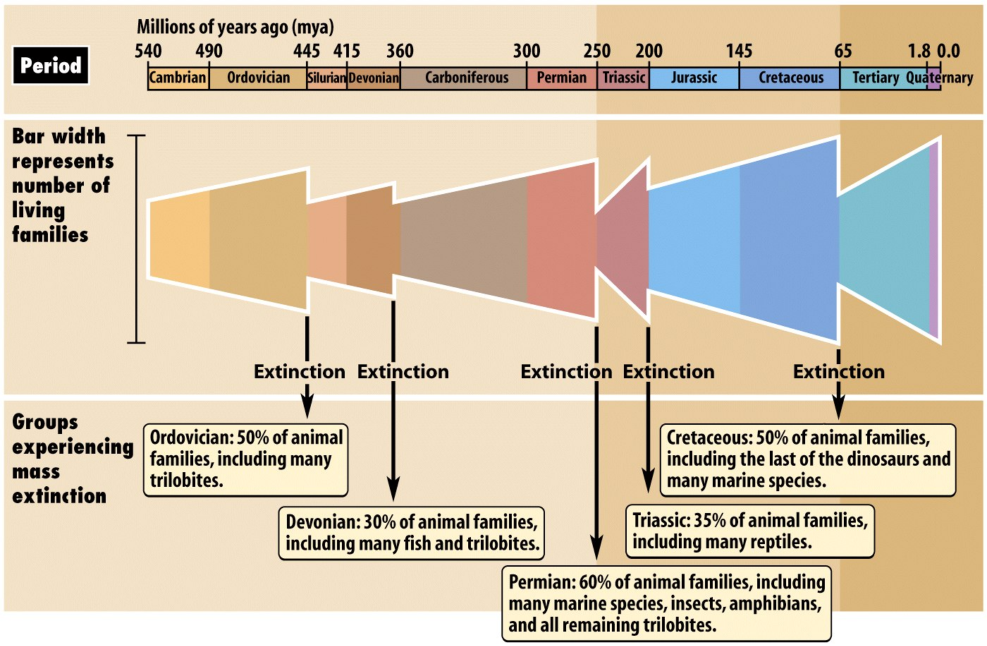
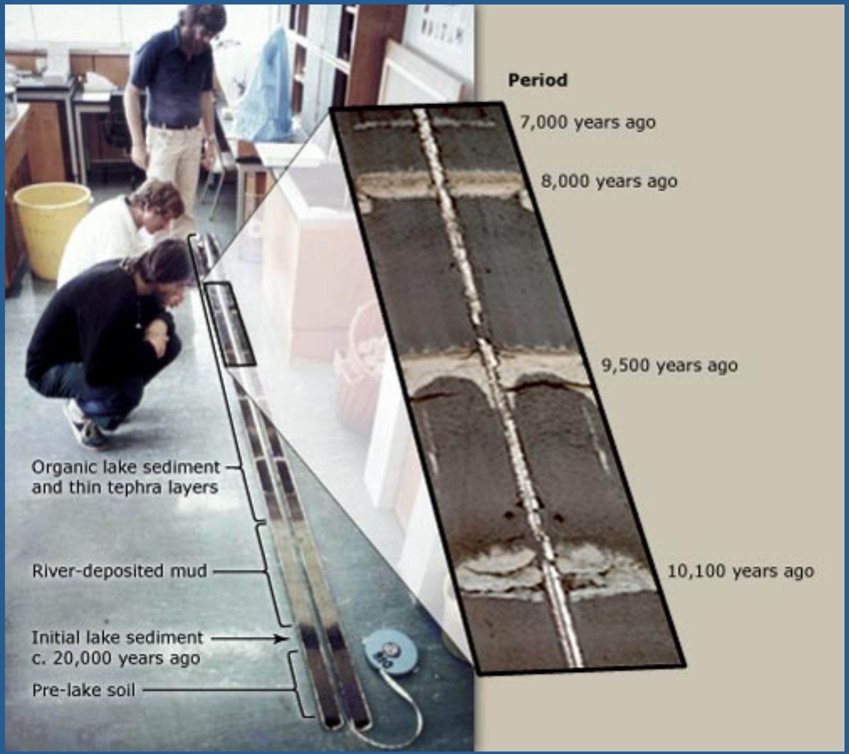


Figure 19-8 Discover Biology 3/e

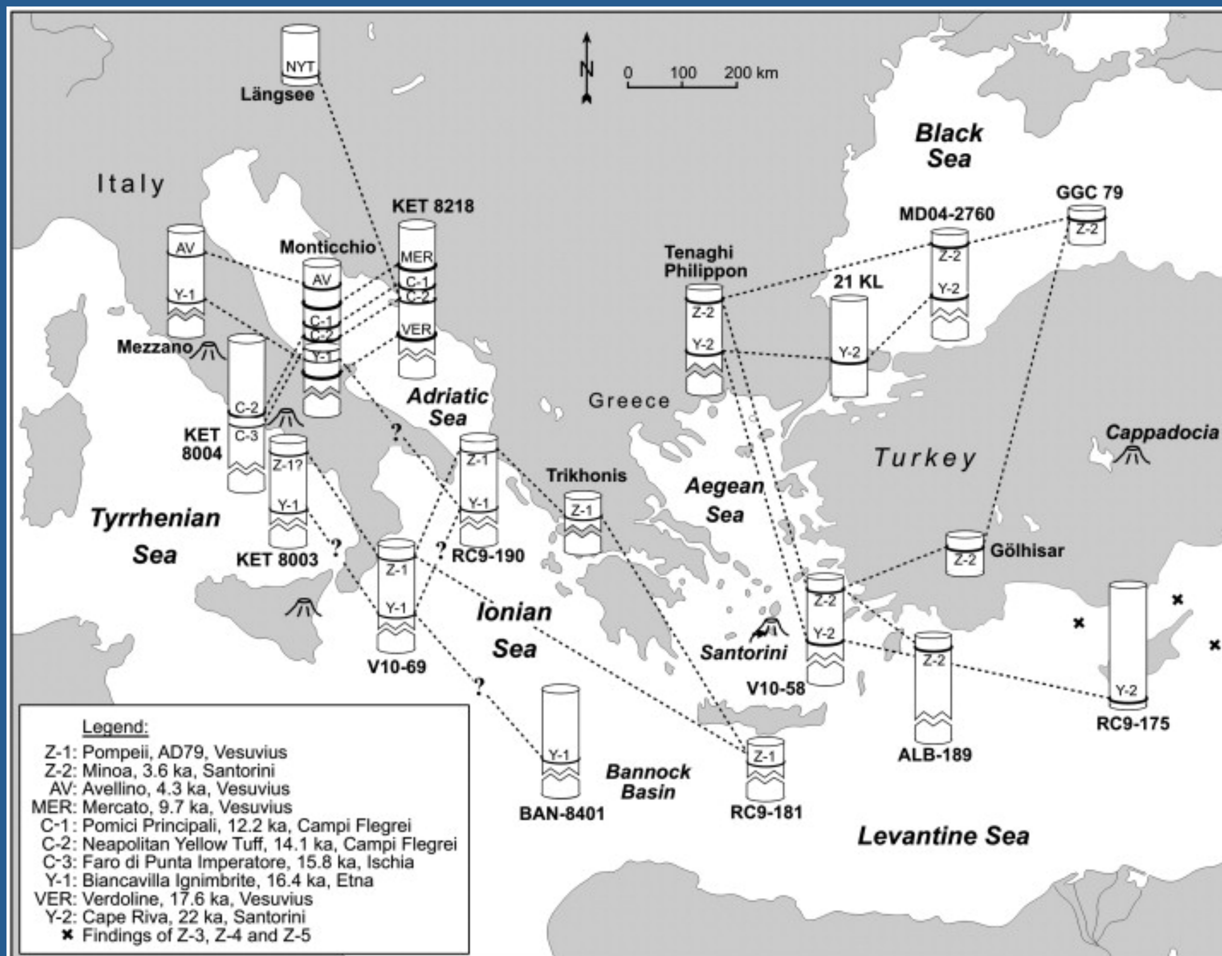
Refinement of the Geologic Time Scale

- The Phanerozoic geologic time scale based on lithostratigraphic and biostratigraphic correlations is a relative time scale that may be refined by a number of techniques including:
  - Tephrostratigraphy
  - Magnetostratigraphy
  - Chemostratigraphy
  - Glacial varves
  - Lichenometry
  - Tree rings
  - Coral growth bands

Tephrostratigraphy



Tephrostratigraphy



Wulf et al. (2008)

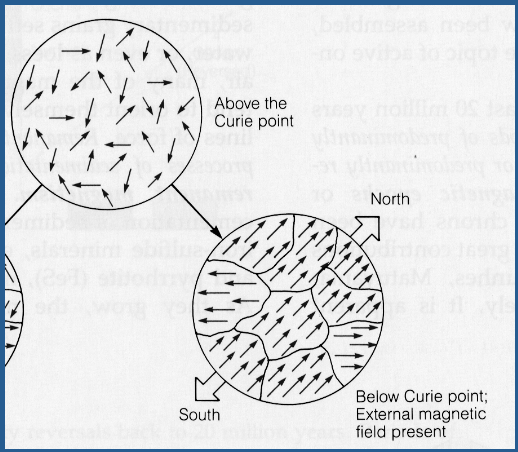
Magnetostratigraphy

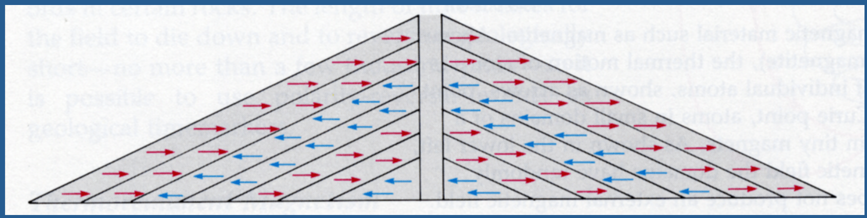
- Certain mineral grains in stratigraphic successions of lavas or sediments, such as magnetite, Fe_3O_4, can record Earth's magnetic field orientation, either by thermoremanent magnetization or by depositional remanent magnetization.

Thermoremanent Magnetization

- As magnetite crystallizes in a lava and cools below the Curie point at a temperature of about 500°C, the magnetic domains in the mineral grains become statistically aligned with the local magnetic field at the location of the eruption of the lava.

- Successive lava flows may record several magnetic field reversals.





Depositional Remanent Magnetization

- Magnetite grains transported along with other sediment particles become aligned with the local magnetic field as they settle through water, and this orientation is preserved as the sediments are lithified.

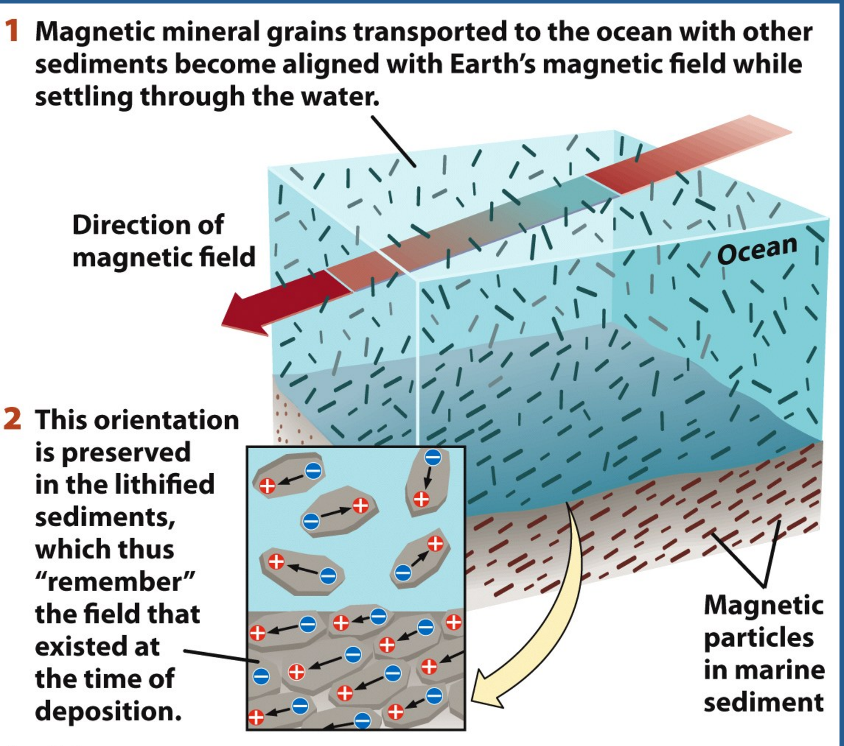


Figure 14.16
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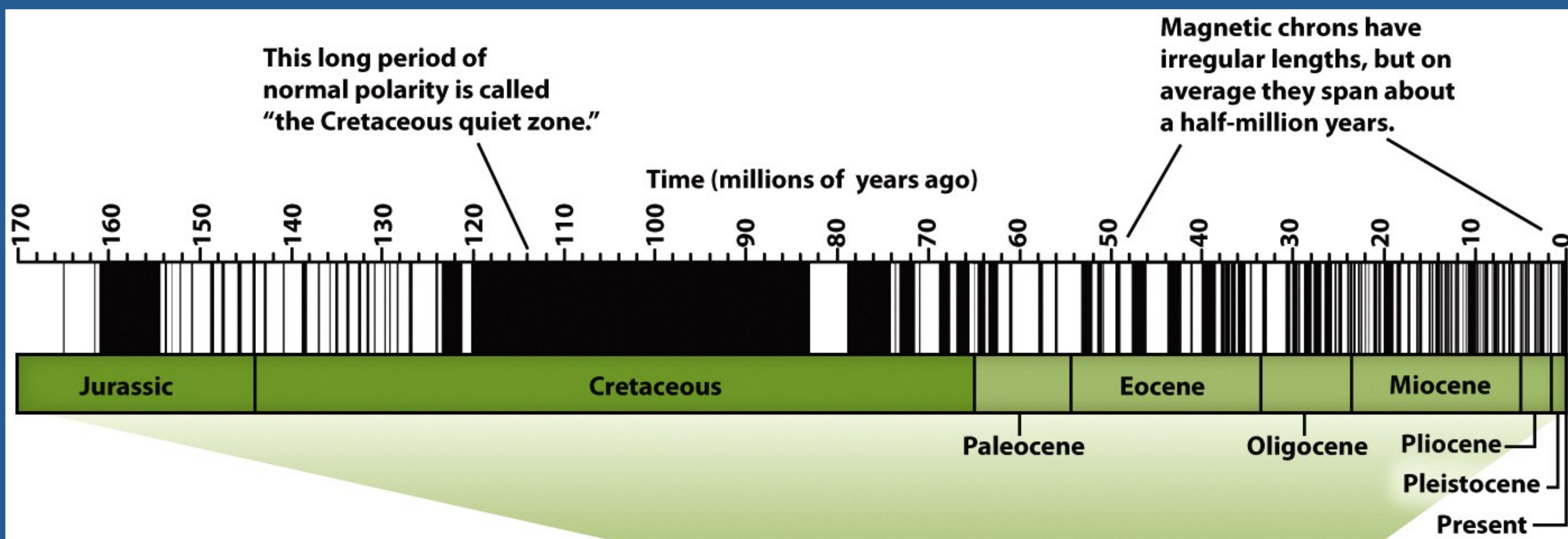
Paleomagnetic Time Scale

- A record of normal and reversed magnetic field polarity that can be used to correlate stratigraphic units now extends back to 250 Ma.



Chemostratigraphy

- Unusual minor element and trace element compositions, or anomalies, characterize certain global stratigraphic horizons and the chemical analysis of such horizons is useful in refining the geologic time scale.

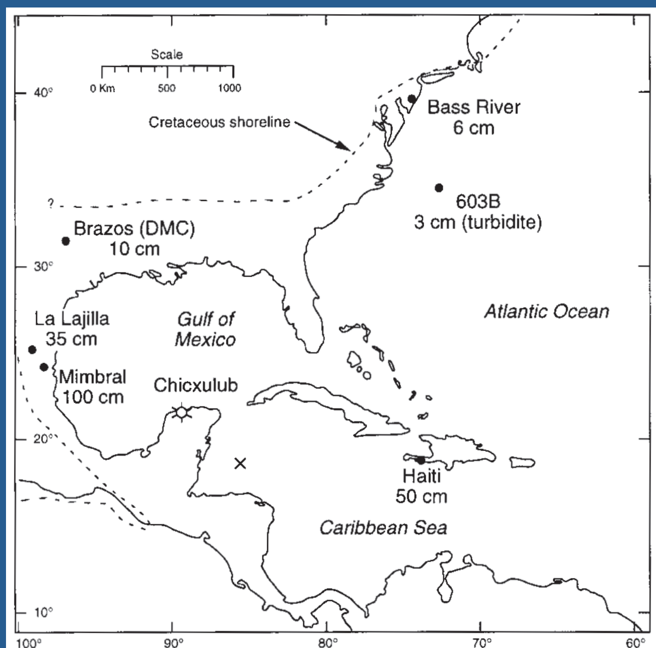
- Arguably the most studied stratigraphic horizon in terms of chemical analysis lies at the Cretaceous-Paleogene boundary, which coincides with the impact of a large meteorite with the Earth, the eruption of the Deccan Traps in India, and a mass extinction.

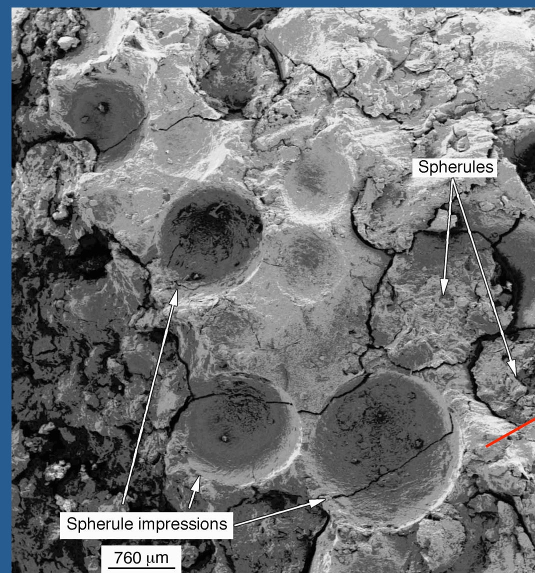
Chicxulub Impact

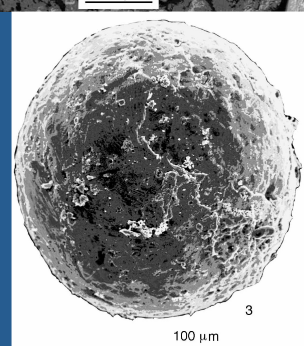
- The impact of a meteorite about 10 km in diameter is thought to have occurred at Chicxulub on the Yucatan Peninsula of Mexico 65 million years ago, at the Cretaceous-Paleogene boundary.

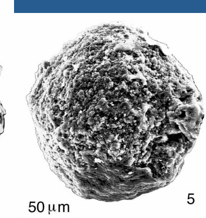
- Evidence from a core drilled at Bass River, New Jersey indicates that glass spherules formed from sediments melted during the impact were ejected and traveled several thousand kilometers in about 10 minutes. The spherules took about an hour to settle through about 100 m of water before being deposited at the top of the Cretaceous mud.

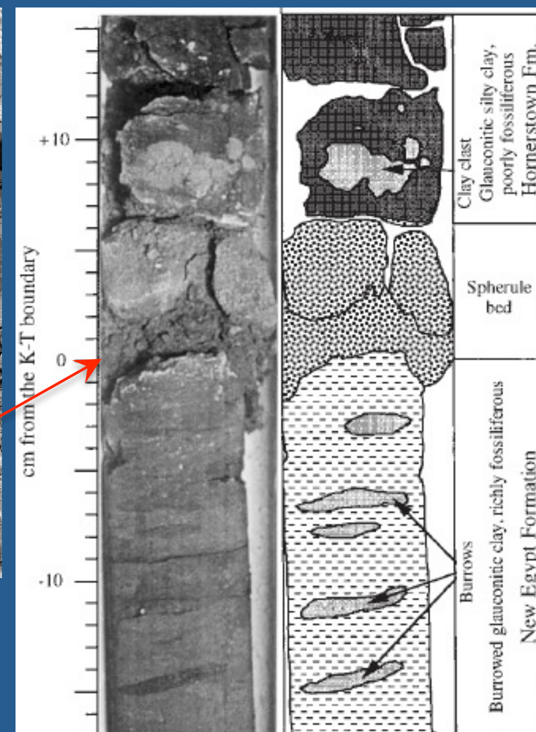
Chicxulub Impact











Olsson et al. (1997)

Chicxulub Impact

- The iridium concentration in a non-marine section at the Cretaceous-Paleogene boundary in New Mexico is about 100 times higher than its typical concentration in the crust of about 300 parts per trillion.

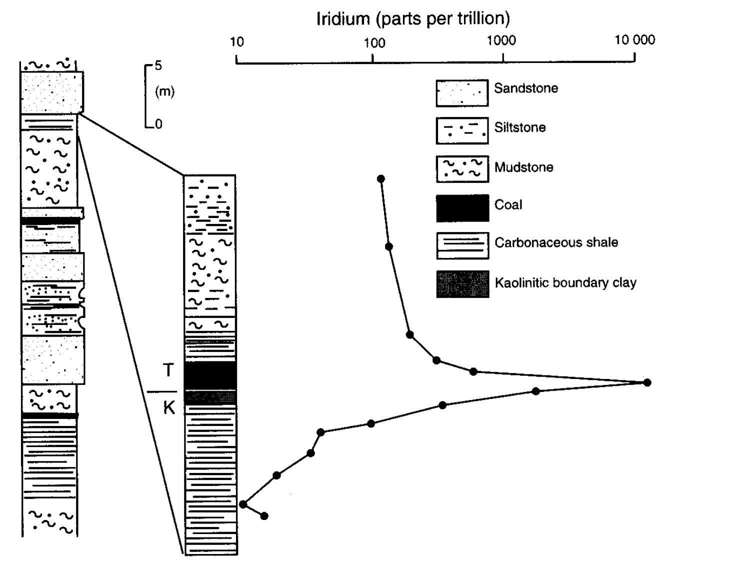
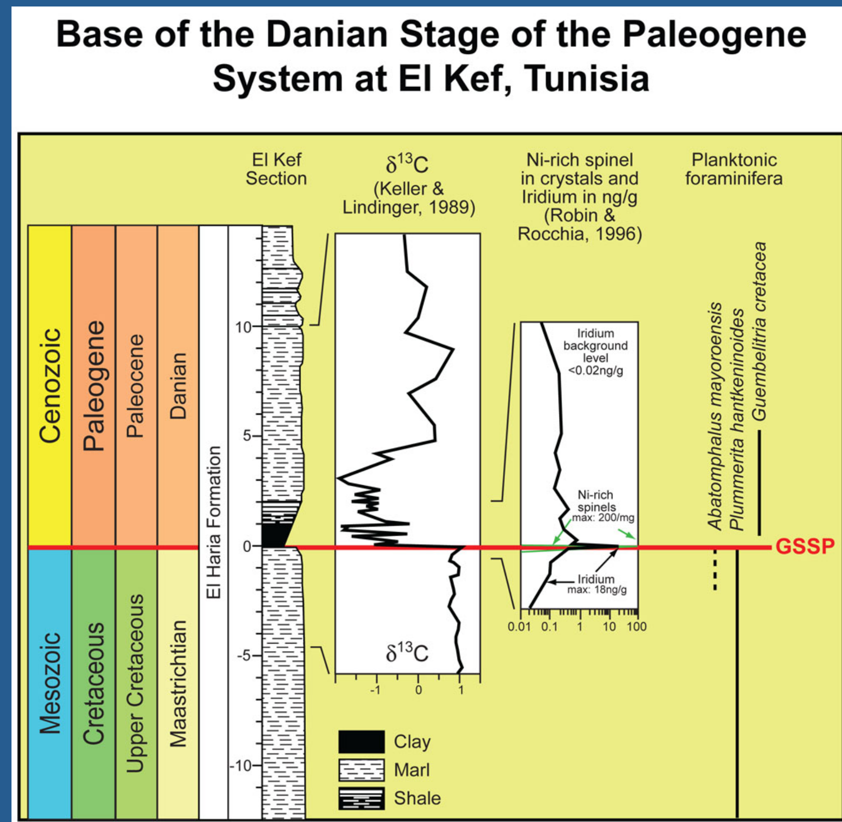


Figure 4.7 *A chemical event horizon. The element iridium is concentrated into a distinct layer, or 'spike', at the Cretaceous–Tertiary boundary in this section from New Mexico. The iridium spike is probably a product of a meteorite impact (see Box 10.4). [Modified from: Kauffman (1988)* Annual Review of Earth & Planetary Sciences **16**, *Figure 7, p. 624]*

Chicxulub Impact

- Spinels richer in Ni and Fe^{3+} than typical terrestrial spinels have also been found at the Cretaceous-Paleogene boundary and appear to have formed by condensation from the Chicxulub impact vapor plume.



Isotopes

- Atoms of the same element with different numbers of neutrons are called isotopes of the element. For example, all carbon isotopes have 6 protons, but may have 6, 7, or 8 neutrons, giving atomic masses of 12, 13, or 14, which are written as ^{12}C, ^{13}C, or ^{14}C.
- Stable isotopes are those isotopes which do not decay spontaneously, while radioactive isotopes do spontaneously decay.
- The relative abundances of isotopes of an element are determined by processes that enhance the abundances of some isotopes over others.

Precambrian Carbon Isotope Excursions

- Pronounced negative stable carbon isotope excursions likely related to increased organic and carbonate carbon fluxes to the deep ocean have been used to correlate late Precambrian strata which contain only very few, generally soft-bodied, fossils.

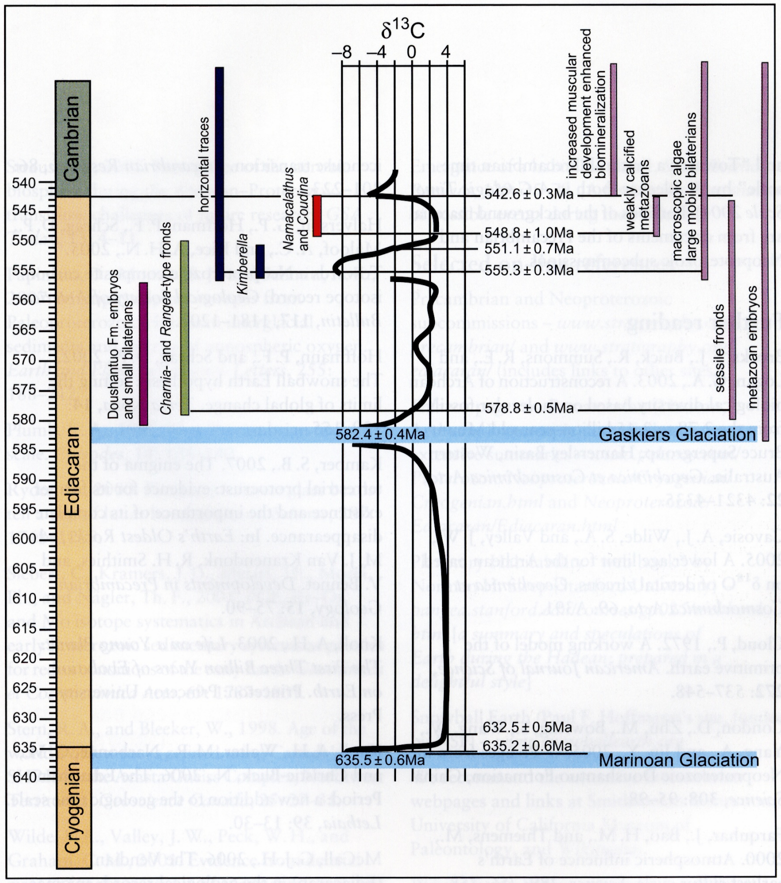
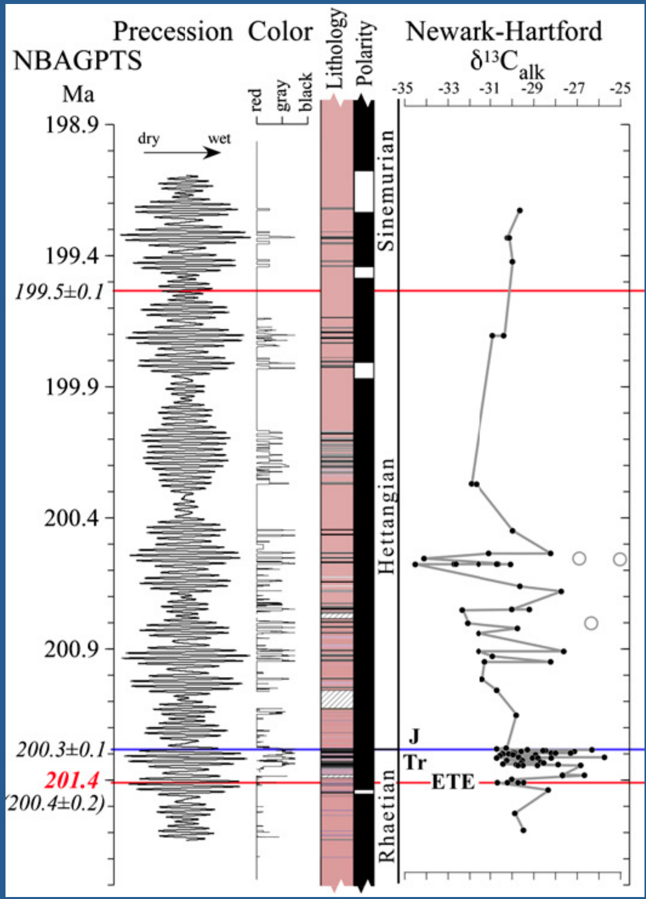


Figure 3.5. Carbon-isotope trends and major biotic events within the Ediacaran Period. [Modified from Fig. 2 of Daniel Condon *et al.*, *Science* 308: 95–98 (1 April 2005), which included data from Myrow and Kaufman, 1999. Used with permission from AAAS.]

Triassic-Jurassic Carbon Isotope Excursions

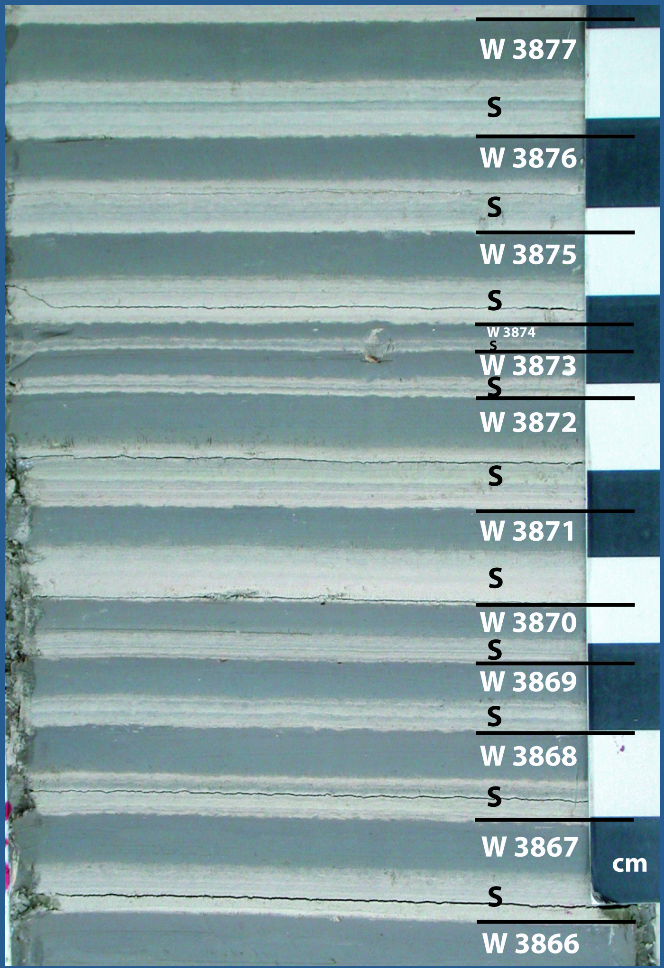
- Analysis of *n*-alkanes derived from leaf wax lipids of lacustrine plants indicate negative stable carbon isotope excursions that have been linked to high atmospheric CO_2 concentrations due to the eruption of flood basalts in the Central Atlantic Magmatic Province (CAMP).



Whiteside et al. (2010)

Glacial Varves

- Glacial varves are annual layers of clay and fine silt-sized particles in glacial and periglacial lake sediments.
- Varves form only in fresh or brackish water because the higher salinity of normal seawater tends to coagulate the clay into coarse grains.



Lichenometry

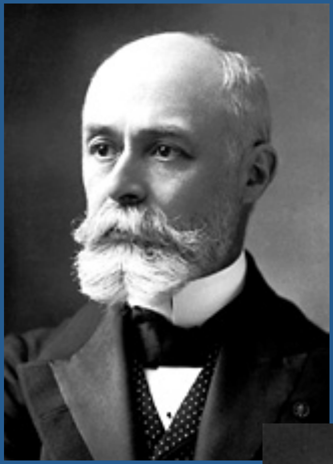
- Lichenometry uses the radial growth rate of lichens to determine the length of time a rock has been exposed.
- Although lichens may be used to date surfaces as old as 10,000 years, they are most accurate when applied to surfaces less than 1,000 years old.

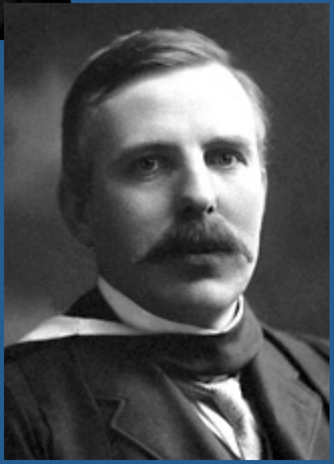
FIGURE 8.10 *Rhizocarpon geographicum*, a long-lived lichen growing on a boulder in a prehistoric rockfall on the south flank of the Mont Blanc Massif, Italy. The lichen is 205 mm in diameter. Based on the measured growth rate of the species in this area, the lichen, and hence the rock fall, is at least 875 years old.

Discovery of Radioactivity

- The discovery of radioactivity in 1896 by French physicist Henri Becquerel paved the way for accurate and precise measurements of absolute geologic ages.

- In 1905, British chemist Ernest Rutherford proposed that the absolute age of a rock could be determined by measuring the decay of radioactive elements found in it.





Radioactive Isotopes

- The nucleus of a radioactive isotope can spontaneously disintegrate, or decay, emitting particles and transforming the parent atom into a daughter atom of a different element.

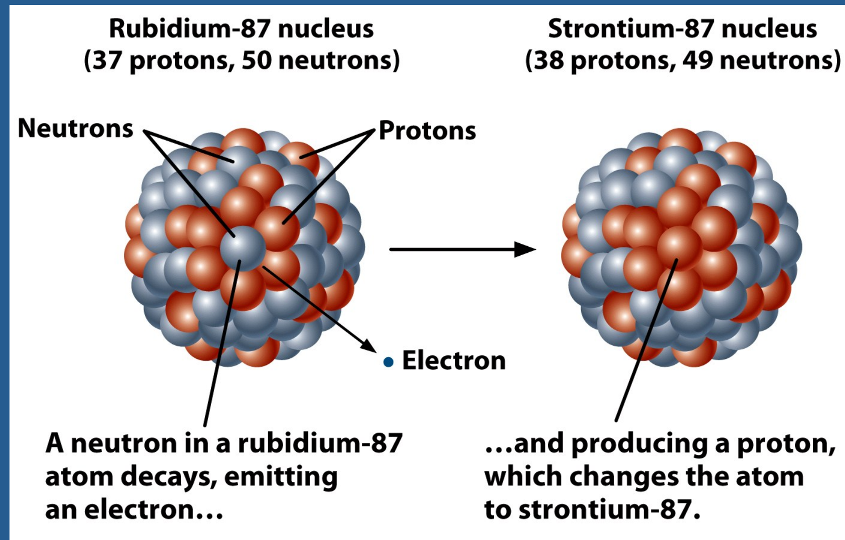


Figure 8.12
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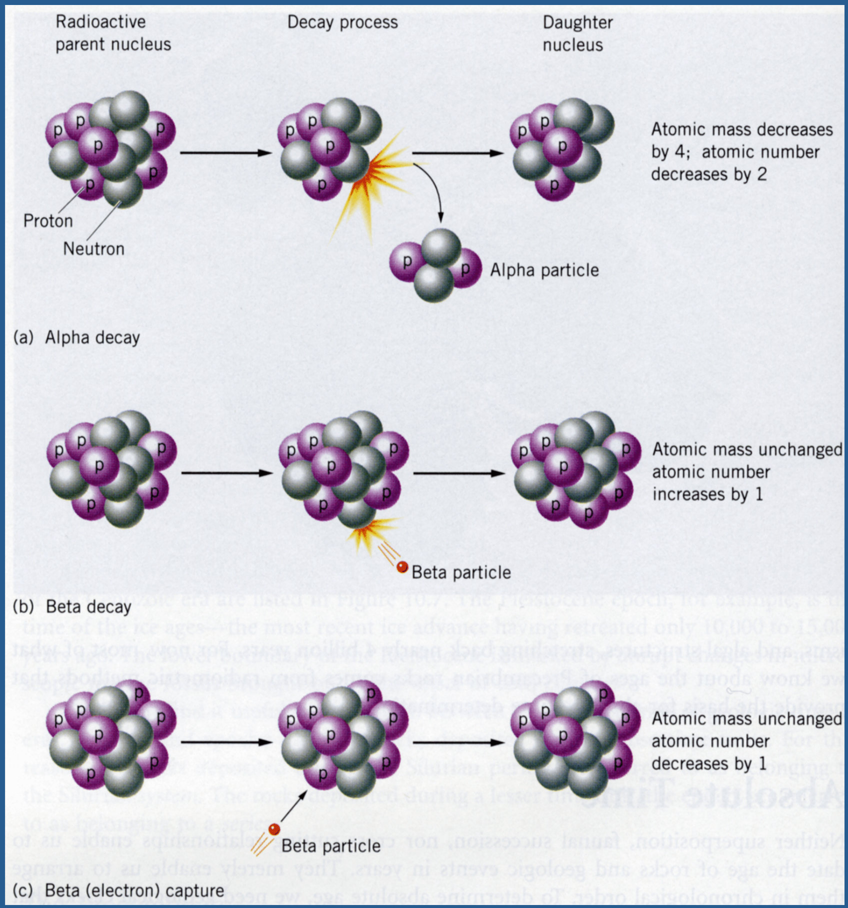
Radioactive Decay

- Example of alpha decay includes the decay of ^{238}U to ^{234}Th.
- Examples of beta decay include the decay of ^{87}Rb to ^{87}Sr and of ^{14}C to ^{14}N.
- Example of electron capture includes the transformation of ^{40}K to ^{40}Ar.



Half-life

- A parent isotope decays into a daughter isotope at a constant rate.

- The rate of radioactive decay is measured by the isotope's half-life: the time required for one-half of the original number of parent atoms to be transformed into daughter atoms.

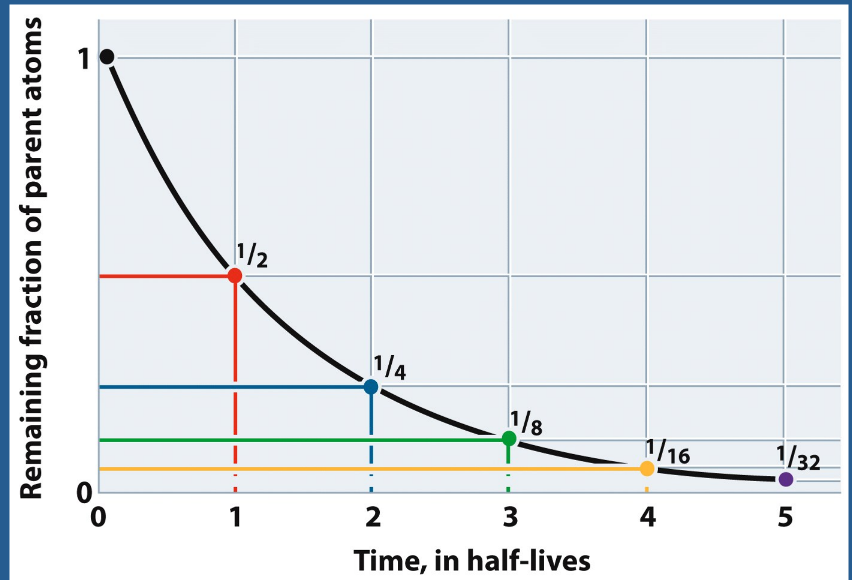


Figure 8.13
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Isotopic Dating

TABLE 8.1 Major Radioactive Elements Used in Isotopic Dating

Isotopes		Half-Life of Parent (years)	Effective Dating Range (years)	Examples of Minerals and Materials That Can Be Dated
Parent	Daughter			
Rubidium-87	Strontium-87	49 billion	10 million–4.6 billion	Muscovite, biotite, orthoclase feldspar
Uranium-238	Lead-206	4.5 billion	10 million–4.6 billion	Zircon, apatite
Potassium-40	Argon-40	1.3 billion	50,000–4.6 billion	Muscovite, biotite, hornblende
Uranium-235	Lead-207	0.7 billion	10 million–4.6 billion	Zircon, apatite
Carbon-14	Nitrogen-14	5730	100–70,000	Wood, charcoal, peat; bone and tissue; shells and other calcium carbonates

Table 8.1
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Isotopic Dating

- Radioactive isotopes make excellent clocks because their half-lives do not vary with changes in temperature, pressure, chemical environment, or other factors that can accompany geologic processes on Earth.
- The initial number of atoms of a radioactive isotope is usually set when a mineral crystallizes from a magma or recrystallizes during metamorphism. During crystallization, however, the number of daughter atoms in a mineral is not necessarily reset to zero, so the initial number of daughter atoms must be taken into account when calculating isotopic age.
- Minerals may lose daughter isotopes by weathering or become contaminated by fluids circulating in rocks.

Uranium-Lead Systematics

- One of the most precise isotopic dating methods for old rocks utilizes the decay of two related isotopes: the decay of ^{238}U to ^{206}Pb and the decay of ^{235}U to ^{207}Pb.

- The two uranium isotopes behave similarly chemically, but they have different half-lives. When used together they may allow the effects of weathering, contamination, and metamorphism to be sorted out.

Absolute Geologic Ages and Eons

- With the advent of isotopic dating techniques, geologists could determine not only the absolute ages of key geologic events that were the basis for the Phanerozoic geologic time scale, but the absolute ages of geologic history over the preceding four billion years.

- To represent the first four billion years of Earth's history, a division of geologic time longer than the era, called the eon, was introduced. Four eons, based on isotopic ages of terrestrial rocks and meteorites, are now recognized: Hadean, Archean, Proterozoic, and Phanerozoic.

Hadean and Archean Eons

- The Hadean Eon began with the formation of the Earth 4.56 billion years ago. Following a period during which the Earth was intensely bombarded by material from the early solar system, the eon ended 3.9 billion years ago.

- The Archean Eon ended 2.5 billion years ago. The geodynamo and the climate system were established, felsic crust accumulated to form the first stable continental masses, and primitive life evolved during this eon.

Proterozoic and Phanerozoic Eons

- The Proterozoic Eon ended 542 million years ago. By the beginning of this eon, plate tectonic processes were operating much as they do today. The rise of organisms increased the amount of oxygen in the atmosphere.
- The Phanerozoic Eon began 542 million years ago with a great proliferation of life, which continues to the present day having survived five major mass extinctions.

Geologic Time Scale