Exploring Geology
Chapter 9

Geologic Time

Chapter 9: Geologic Time

- Stratigraphic Principles
- Relative Age Dating
- Radioactive Age Dating
- Unconformities
- Fossils
- Geologic Time Scale
- Age of Earth
- Milestones in Geologic History of Earth

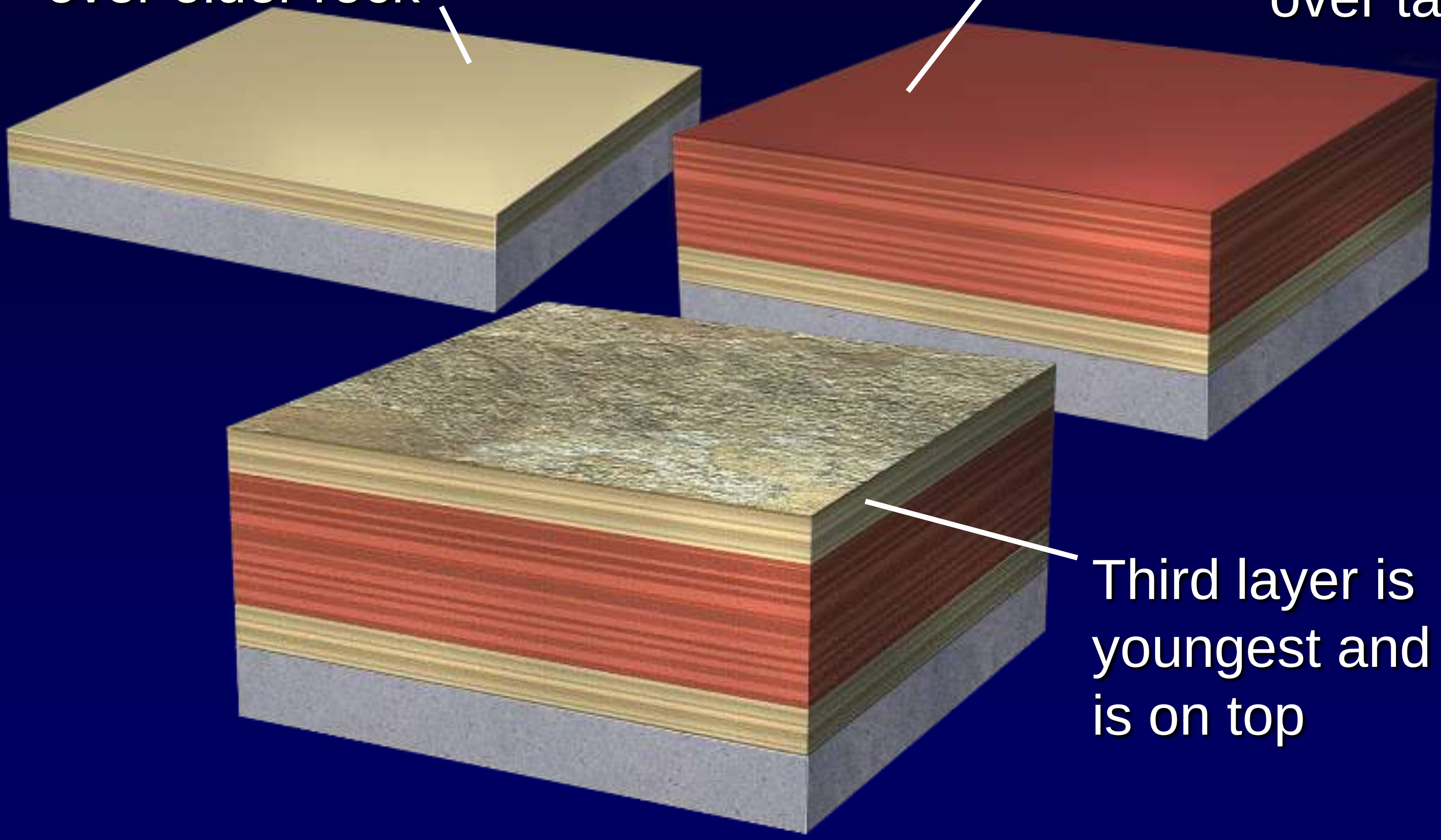
Stratigraphic Principles

- Superposition
- Original Horizontality
- Lateral Continuity
- Cross-Cutting Relationships
- Inclusions
- Faunal succession

Superposition

- Superior (or topmost) layers are later

Younger Units Deposited on Older Units



09.01.a

09.01.a

In the view below?

Observe these layers. Which is oldest and which is youngest?

Original Horizontality

- Sedimentary layers are deposited flat or nearly flat

Observe the layers in these two photographs, which show the same sequence of rocks. What is different and what do you think happened?

09.01.a

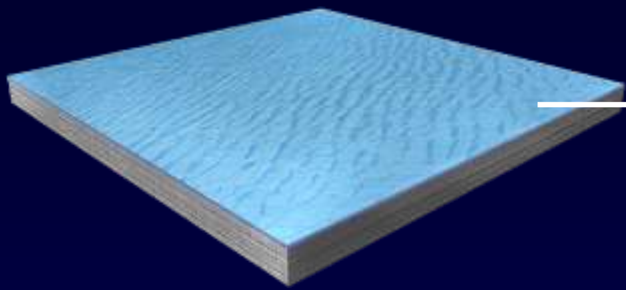
Most sediment is deposited in horizontal layers

If layers are not horizontal, something has happened (deformation)

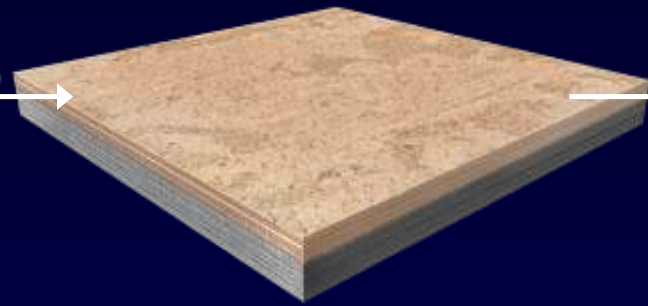
Lateral Continuity

- Most rock layers were originally continuous over large areas, then areas in between similar layers were eroded

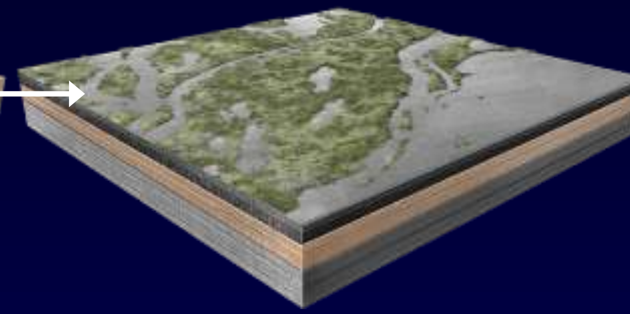
How a Typical Landscape Forms



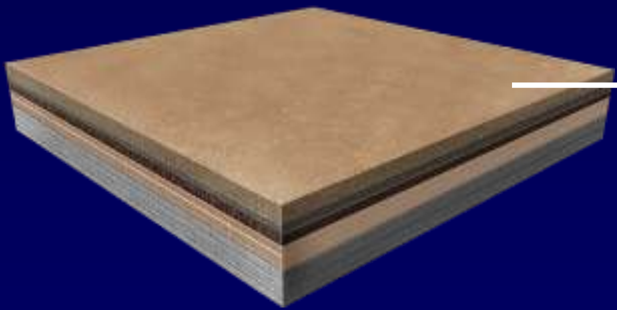
Preexisting rock covered by sea



Sea deposits layer of sediment

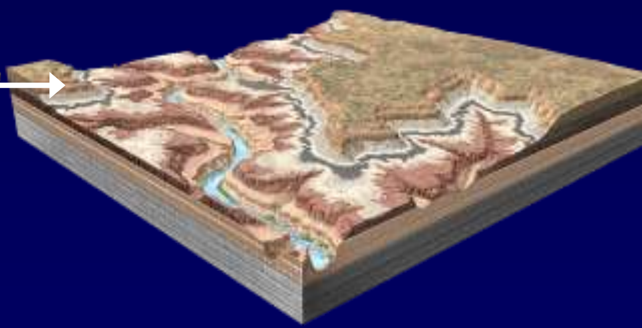


Environment changes, depositing more rock



Deposition stops

Area eroded by rivers, etc.



Continued erosion

Observe this photograph and consider the sequence of events that likely occurred

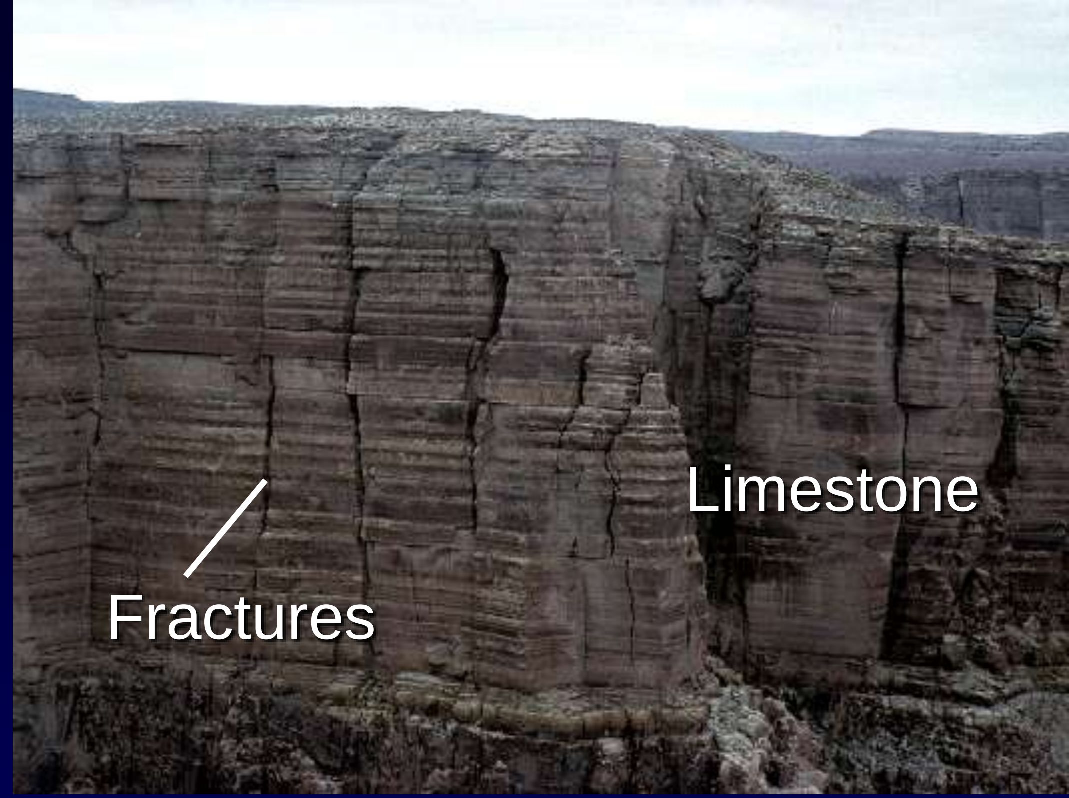
09.03.a1

Cross-Cutting Relationships

- Whatever cuts across, had to come later than what it cuts

Younger Rock or Feature Can Crosscut an Older Rock or Feature

Determine which rock or feature is younger in each image



Exercise - cross cutting

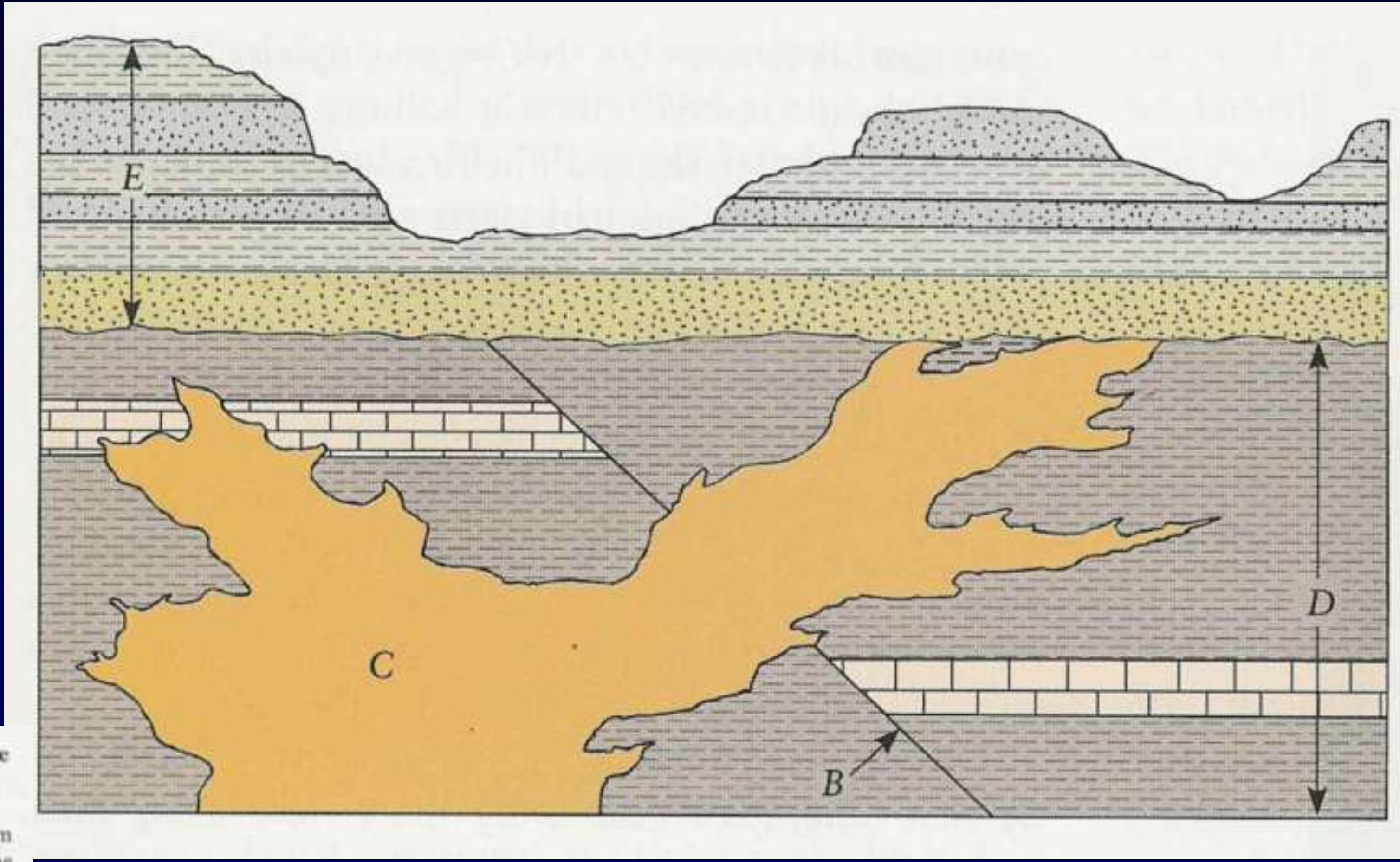


FIGURE 1-11 An example of how the sequence of geologic events can be determined from cross-cutting relationships and superposition. From first to last, the sequence indicated in the cross-section is first deposition of *D*, then faulting to produce fault *B*, then intrusion of igneous rock mass *C*, and finally erosion followed by deposition of *E*. Strata labeled *D* are oldest, and strata labeled *E* are youngest. *How do you know that the intrusion of C occurred after the formation of the fault?*

Younger Rocks and Features Can Cause Changes Along Contacts with Older Rocks

Observe the boundaries between different rock types

Inclusions

- Whatever is included came before what encompasses or includes it
- It can’t be included unless it was already there

Inclusions

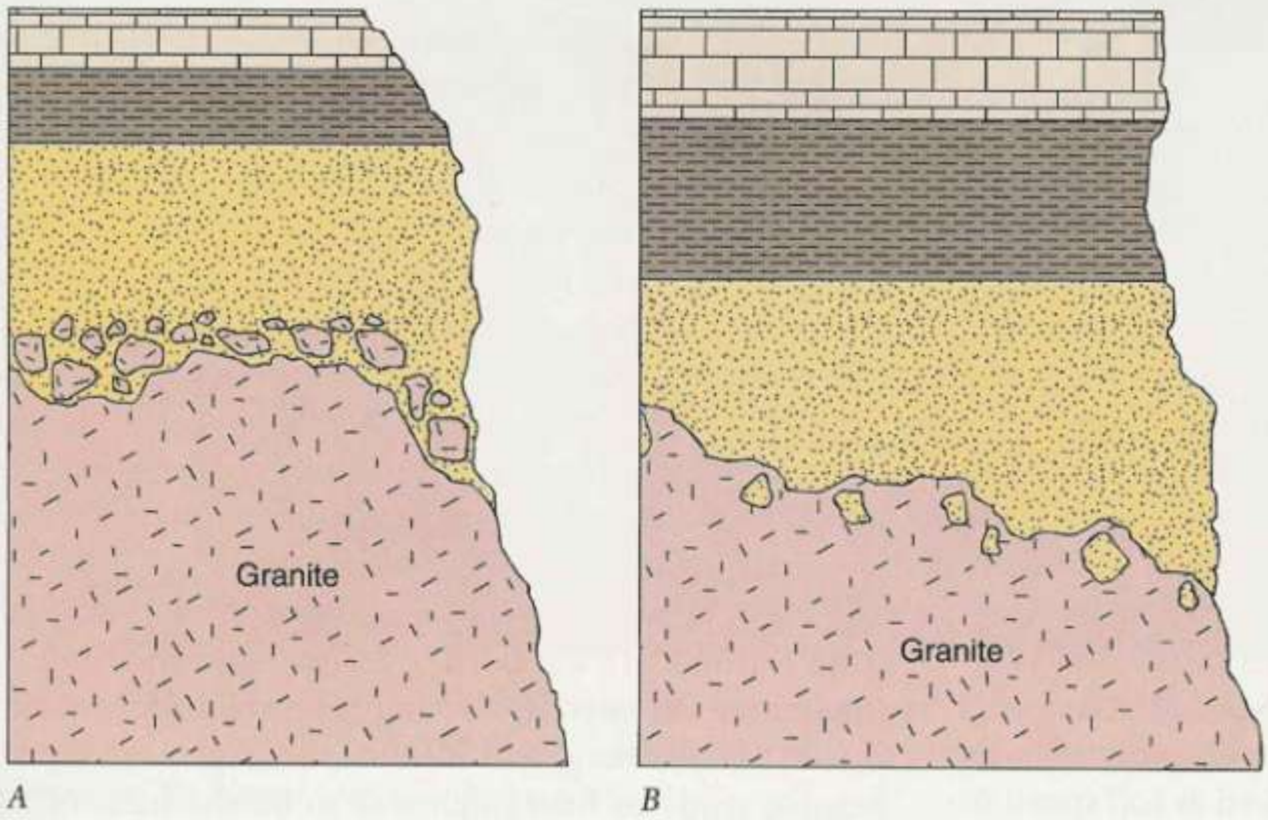


FIGURE 1-12 (*A*)Granite inclusions in sandstone indicate that granite is the older unit. (*B*) Inclusions of sandstone in granite indicate that sandstone is the older unit. *If the granite in (A) was found to be 150 million years old, and the shale above the sandstone 100 million years old, what can be stated about the age of the sandstone?*

Younger Sediment or Rock Can Contain Pieces of Older Rock

Determine which rock is younger in each image

Faunal Succession

- Fossils succeed one another in a sequence that can be pieced together from various localities.
- This sequence is the same in different areas.

How Are Fossils Preserved?

09.05.a

Traces of Creatures in Rock Record

Footprints

What are some aspects of a creature you could infer from a sequence of footprints?

Burrows of worms, etc.

How would you try to figure out what kind of creature made a particular kind of burrow?

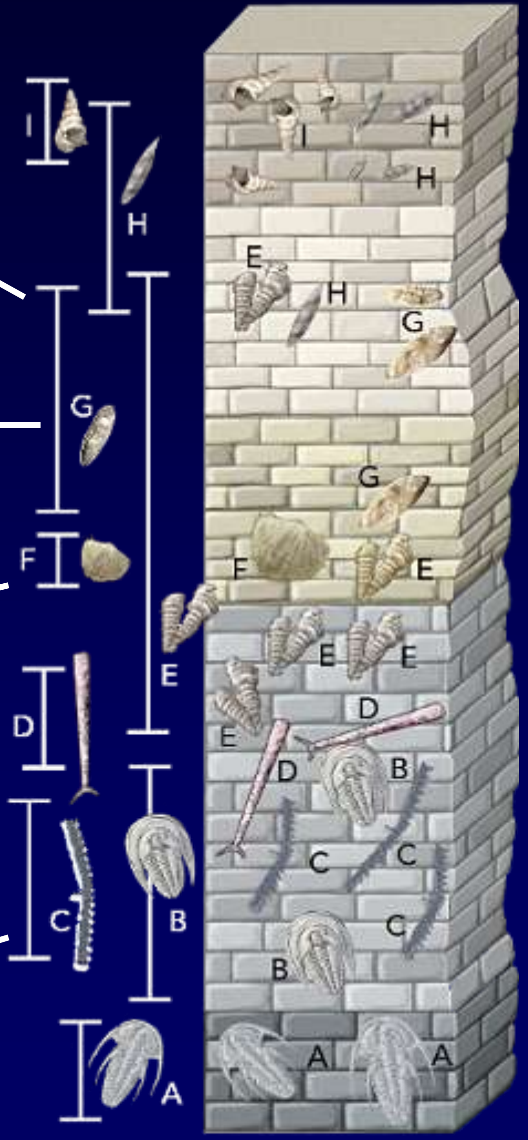
How Fossils Change in Sequence of Sedimentary Rocks

Can use overlap of two fossils to constrain age

Some spanned long times

Some species lived short time span so give narrow age range

Fossils change up section in systematic way



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How Fossils Vary with Age

Mammals and grasses

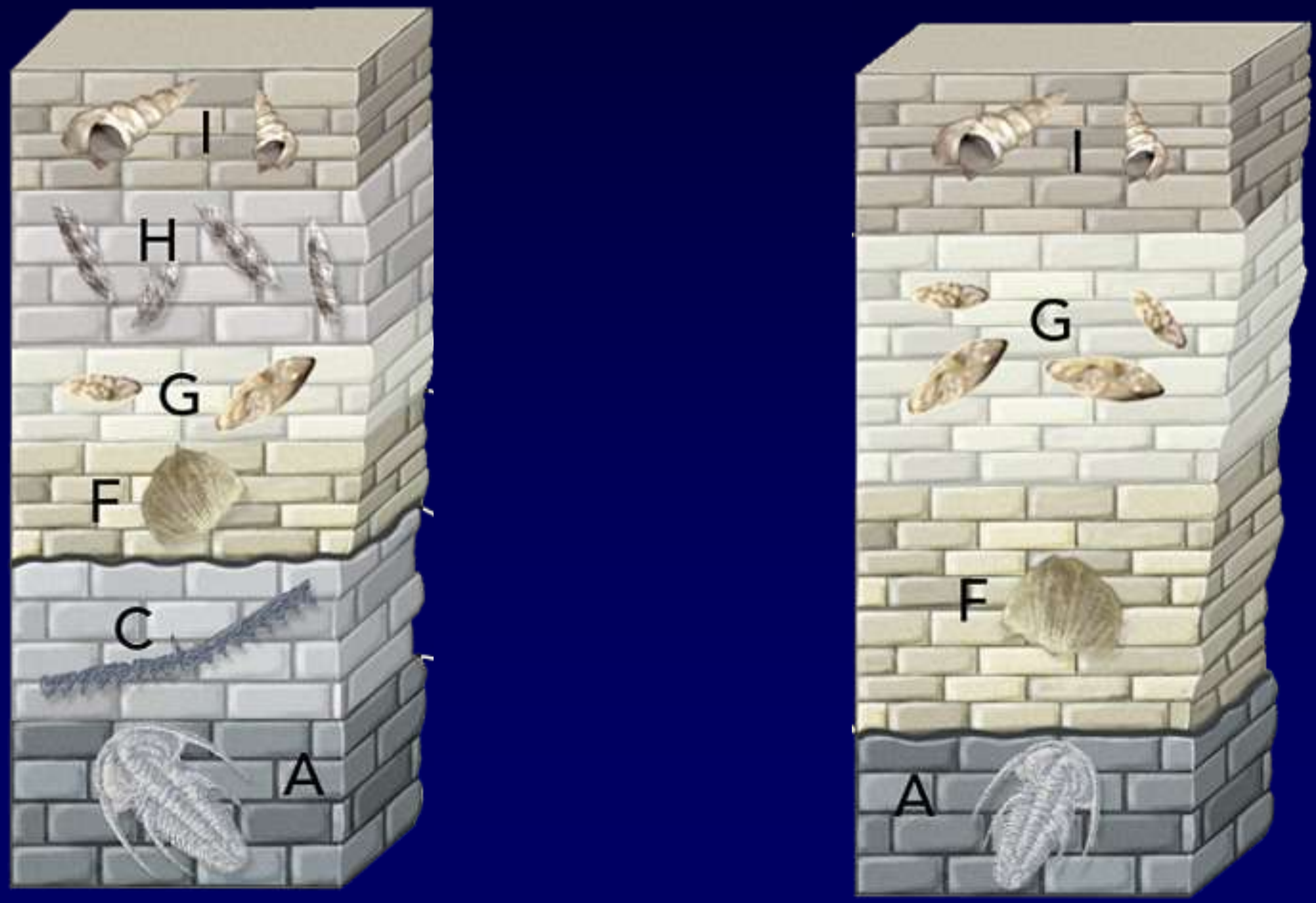
Dinosaurs and flowering plants

Crinoids, coral, clams, certain fish, plants, insects, and amphibians

Simple creatures and fossils, such as stromatolites

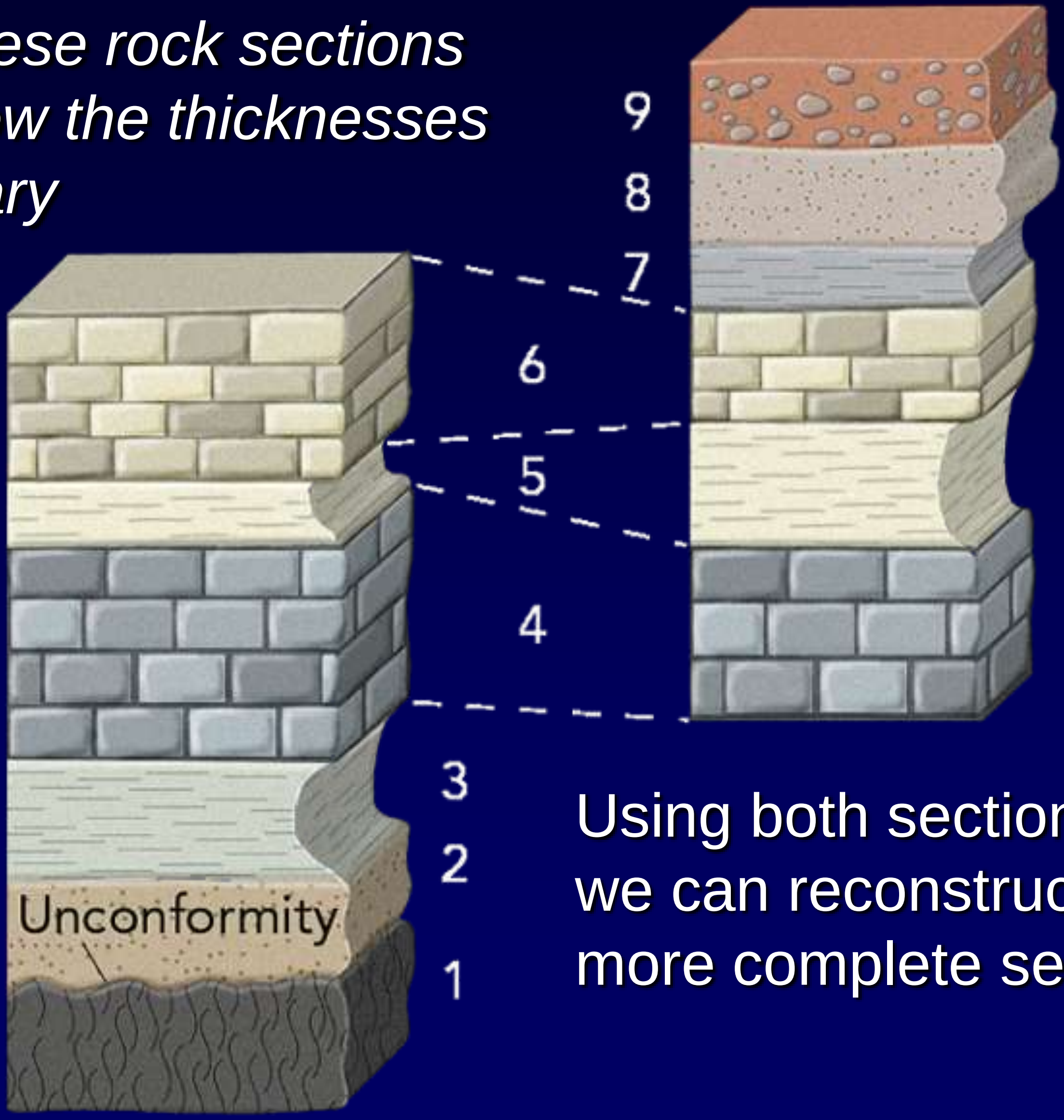
09.06.a

These two sections of rock contain many of the same fossils. Match the two sections, envisioning dashed lines connecting places where the two sections correlate (i.e., represent the same time).



Comparing Partly Overlapping Sections

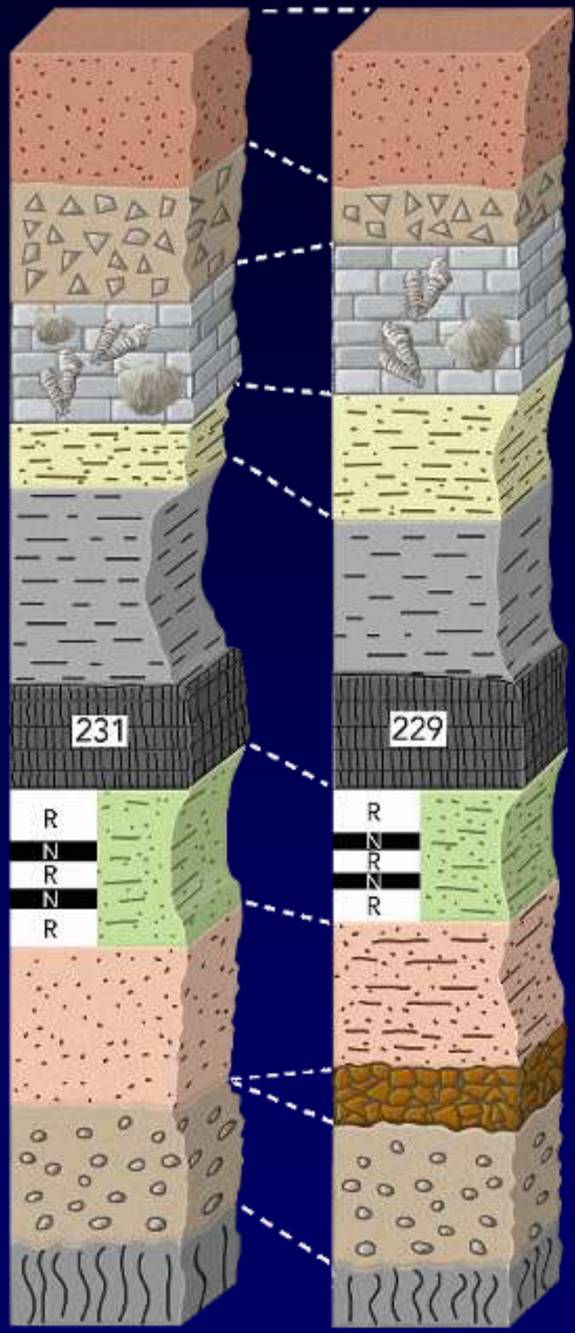
Observe how these rock sections correlate and how the thicknesses of some units vary



Using both sections, we can reconstruct a more complete section

Correlating Units and Events

Observe these two sections, noting how each layer correlates or doesn't from one section to another

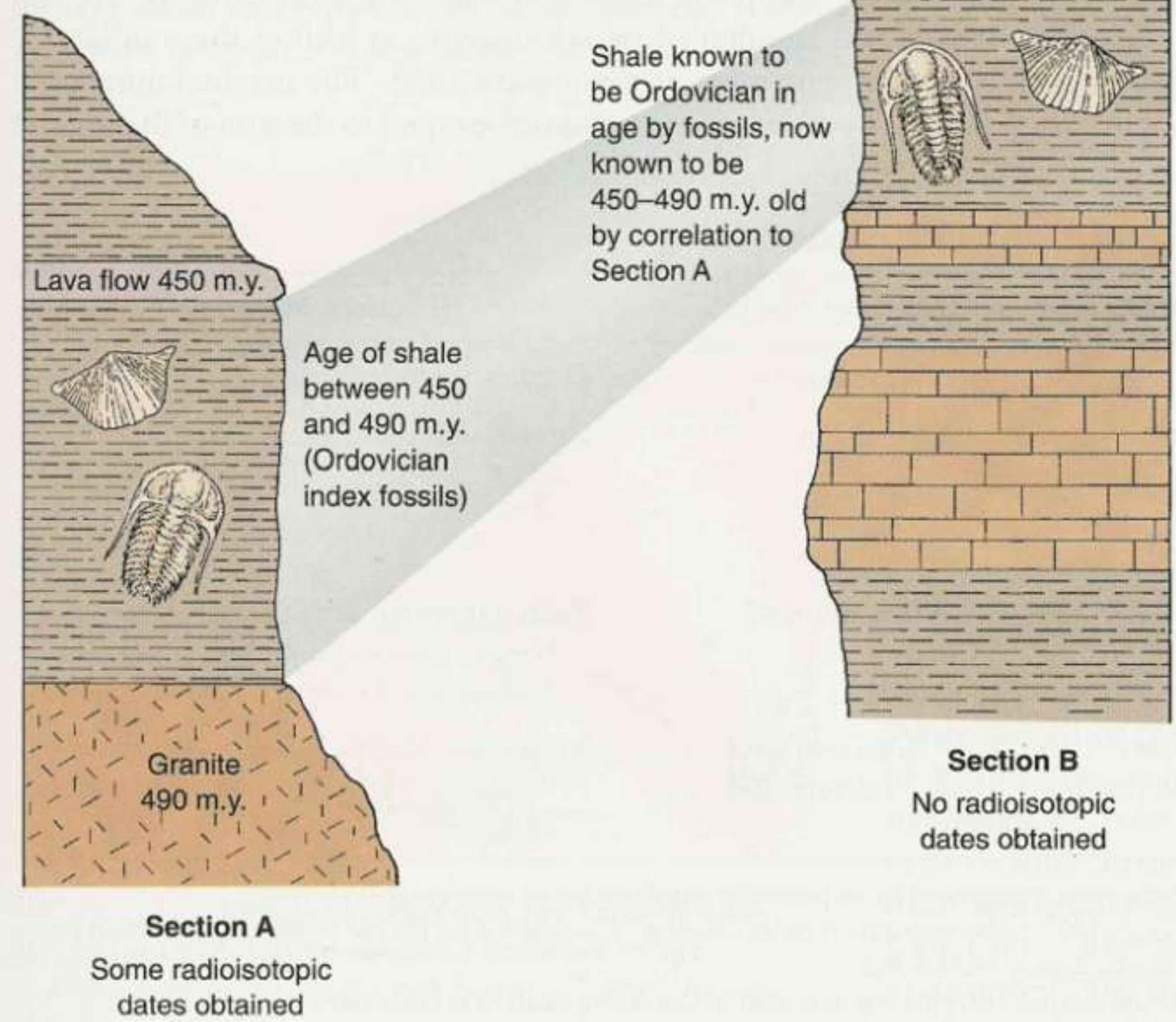


Can use:

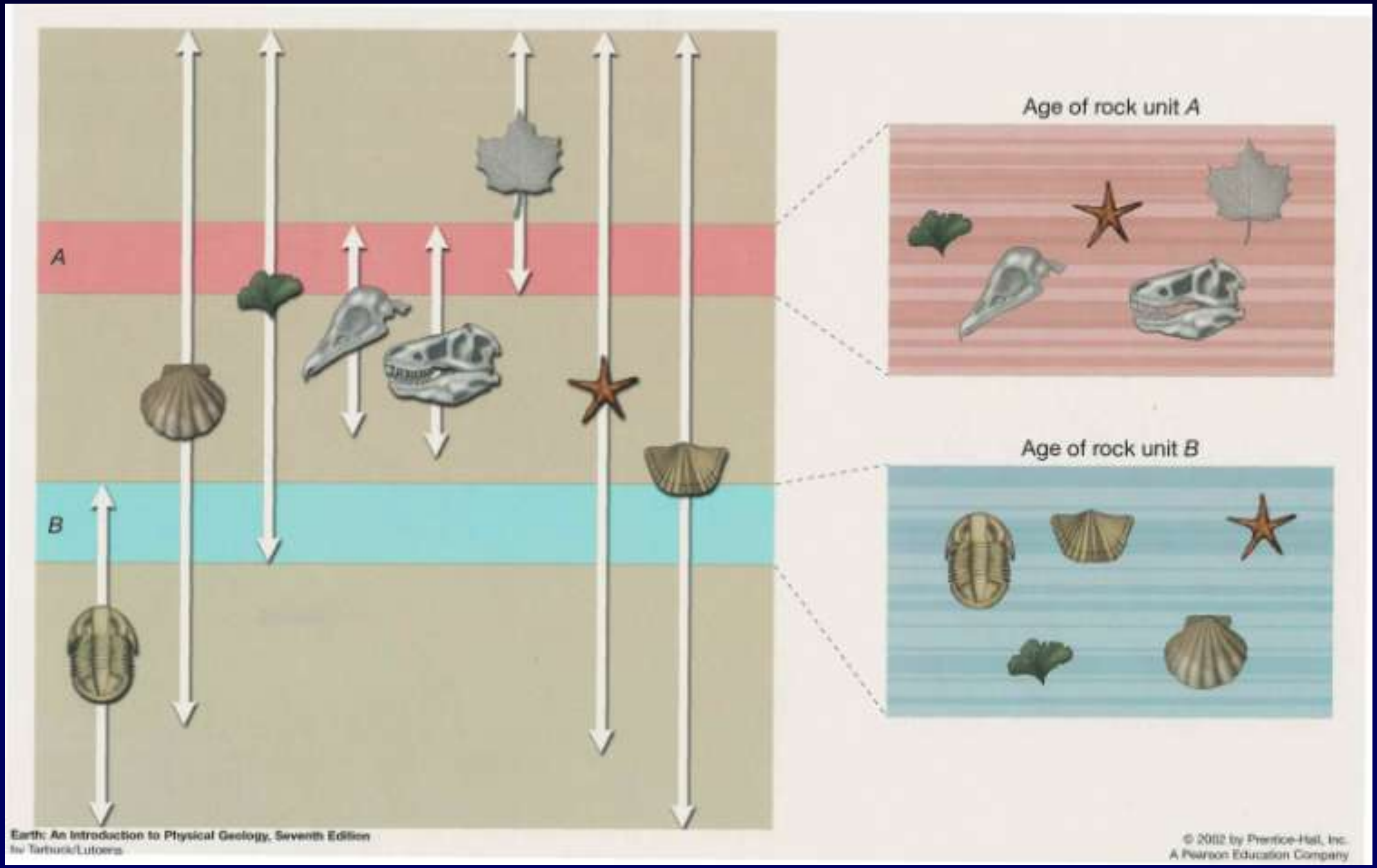
- Rock type
- Position in sequence
- Fossils
- Numeric ages
- Magnetic sequence

09.12.a1

Dating Fossils



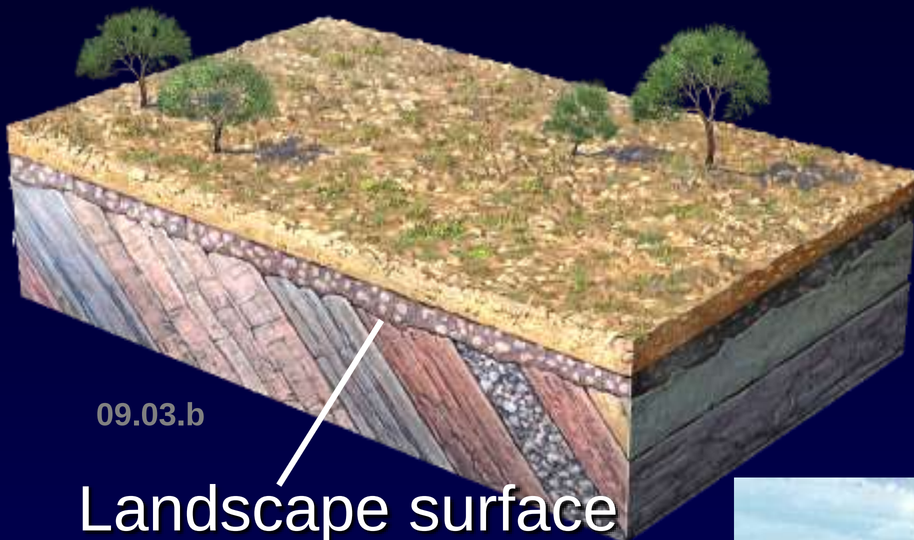
Fossil assemblages

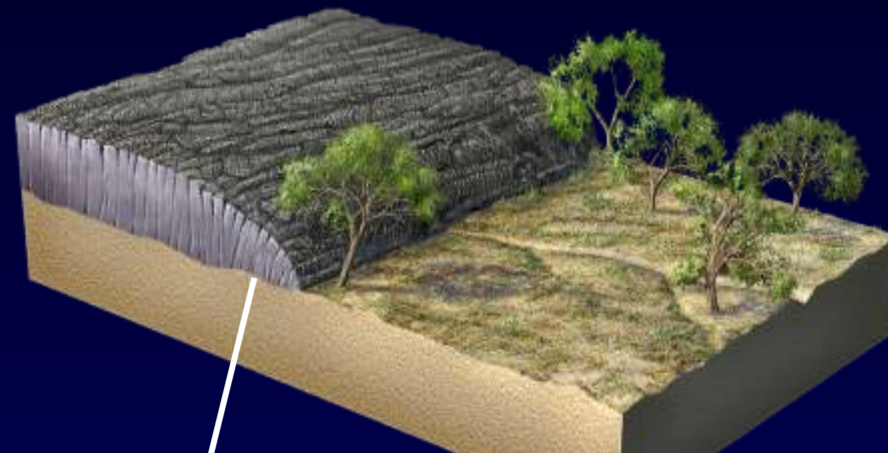


Observe this photograph and consider the sequence of events that likely occurred

09.03.a2

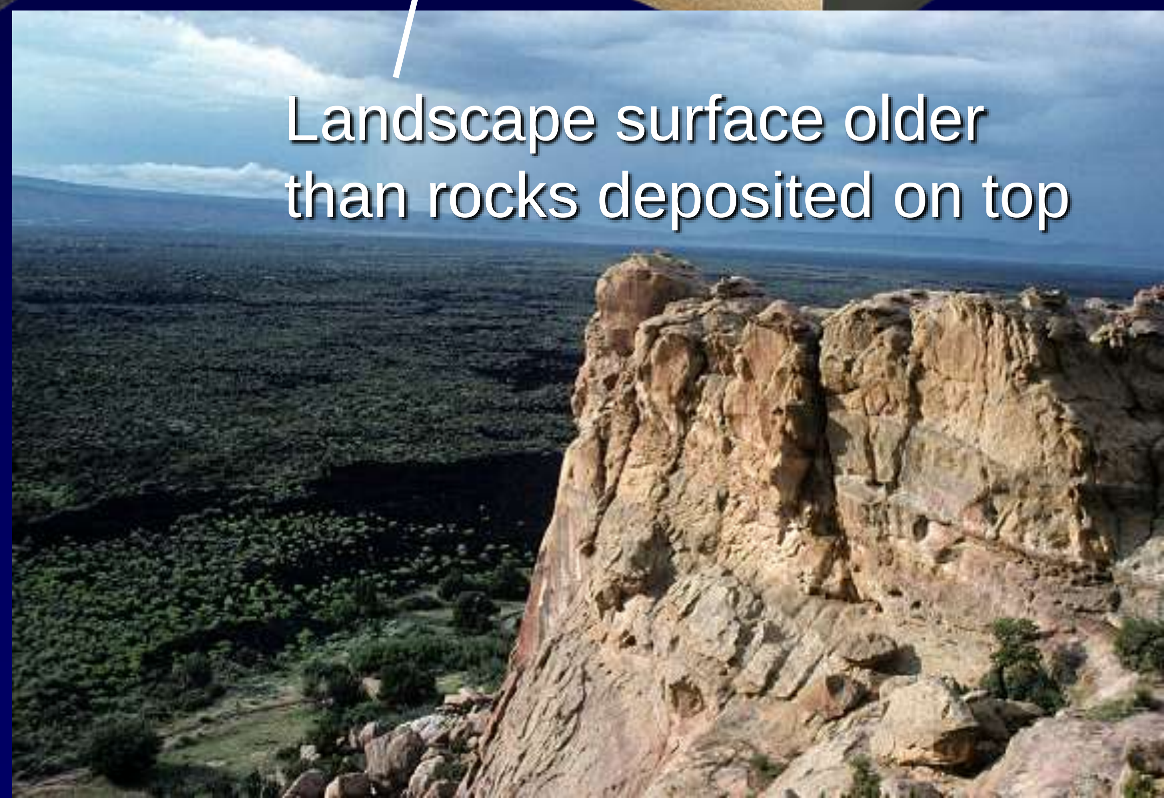
Determining Ages of Landscapes





Landscape surface younger than rocks on which it is carved

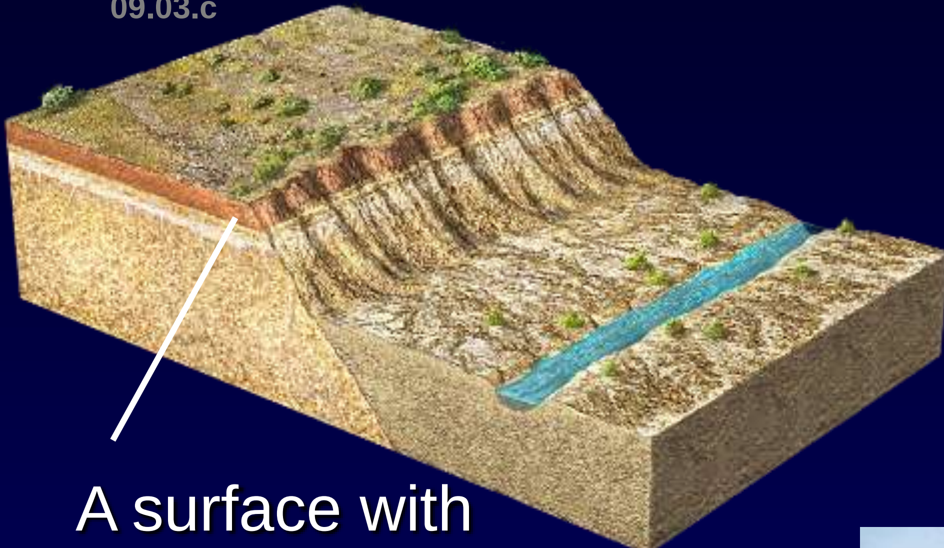
Landscape surface older than rocks deposited on top



This photograph shows a dark basalt flow in a valley, next to a cliff of tan sandstone. What can you say about the age of the landscape?

Other Indications of Landscape Age

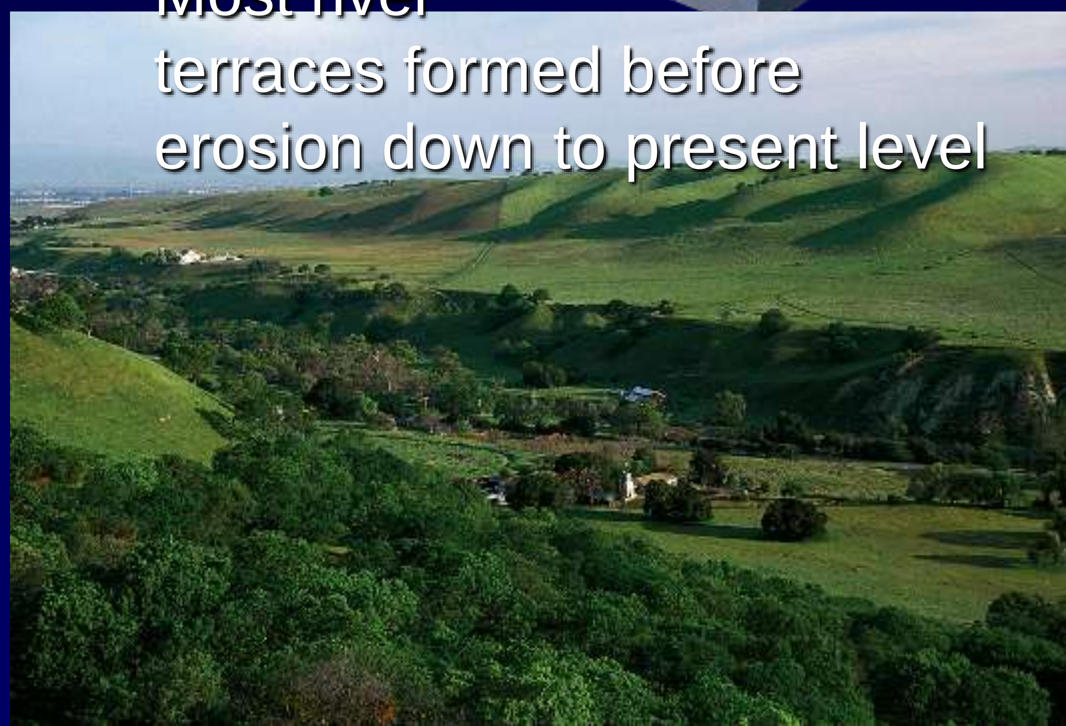
09.03.c



A surface with well-developed soil is older than one with less soil

Most river terraces formed before erosion down to present level

In this scene, consider relative ages of different levels in the landscape. If you were there, how could you test your interpretation?

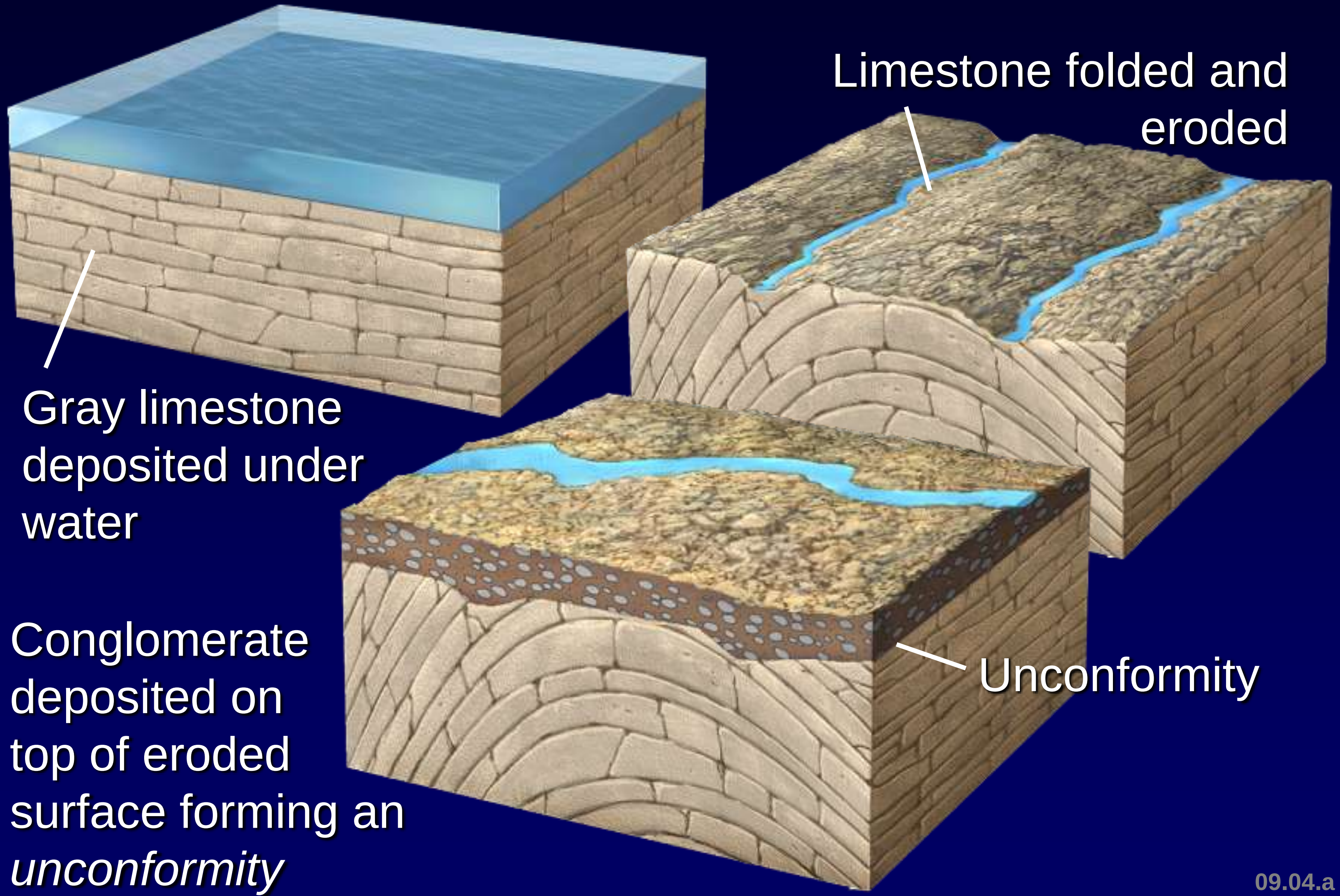


Unconformities

- Angular unconformity
- Nonconformity
- Disconformity

- Missing time, missing rocks/events, usually uplift & erosion

What Does an Unconformity Represent?



Angular Unconformity

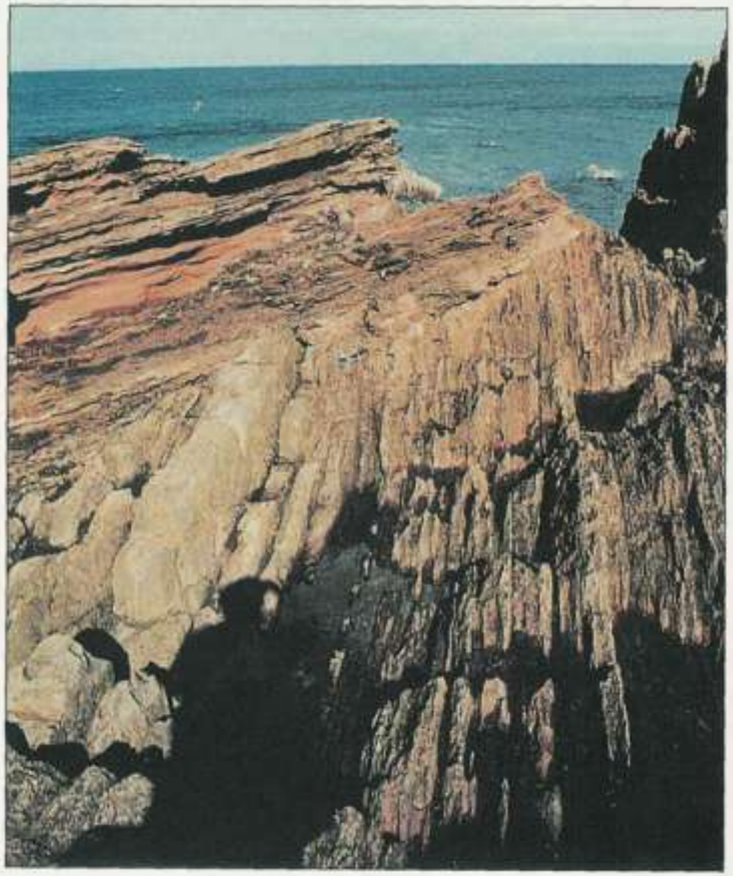
- Layers above are tilted at a different angle than the layers below

Pleistocene angular unconformity

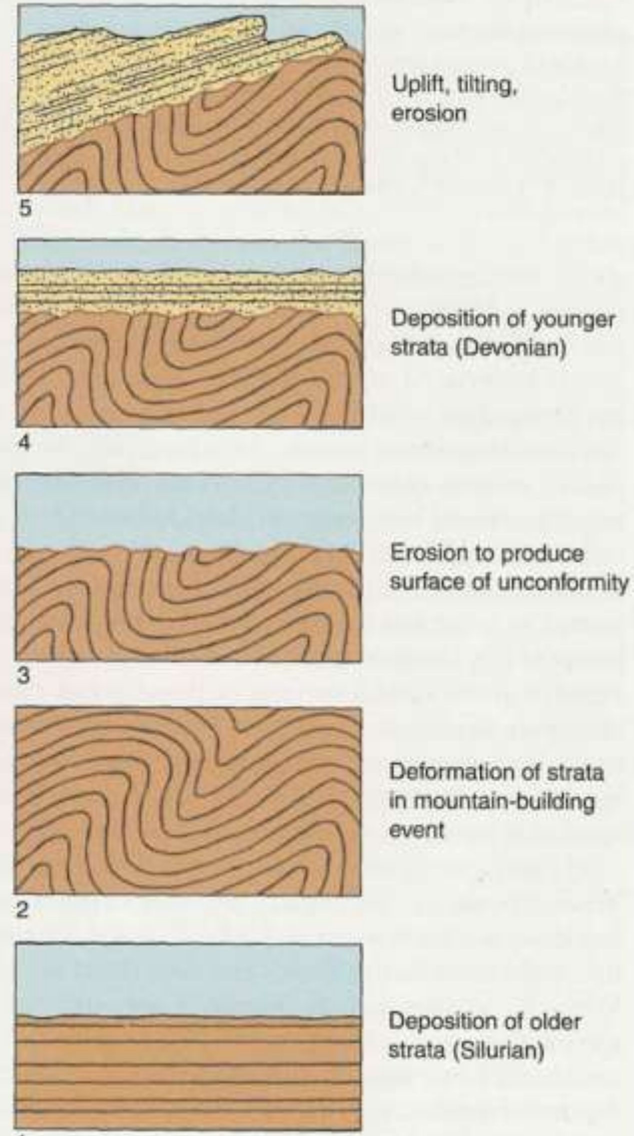
Angular Unconformity: Hutton

Observe the orientation of rocks at Siccar Point, Scotland

Angular Uncon-formity



A



B

FIGURE 1-8 Angular unconformity at Siccar Point, eastern Scotland. (*A*) It was here that James Hutton first realized the historical significance of an unconformity. The drawings (*B*) indicate the sequence of events documented in this famous exposure. ? *Which of Steno's laws are illustrated in this rock exposure? (Photograph courtesy of E. H. Hay, De Anza College.)*

Grand Canyon section

Identify the angular unconformity in each photograph

09.04.a

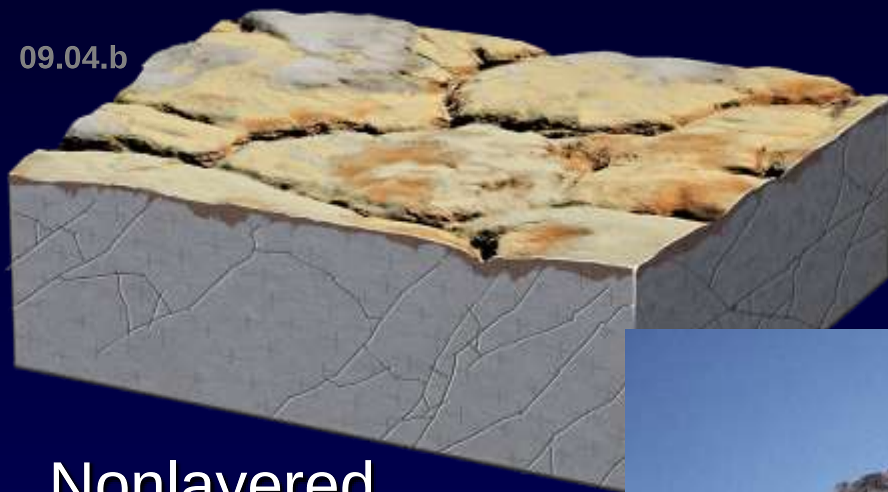
Nonconformities

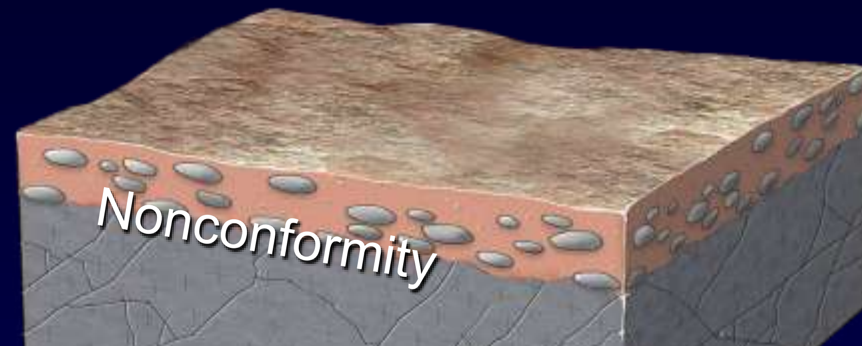
- Different type of rock in contact:
- Sedimentary above igneous or metamorphic
- Igneous in contact with metamorphic

Inner Gorge Grand Canyon: Tapeats on Vishnu Schist, Zoroaster Granite

How Does a Nonconformity Form?

09.04.b





Nonlayered rock uplifted and eroded

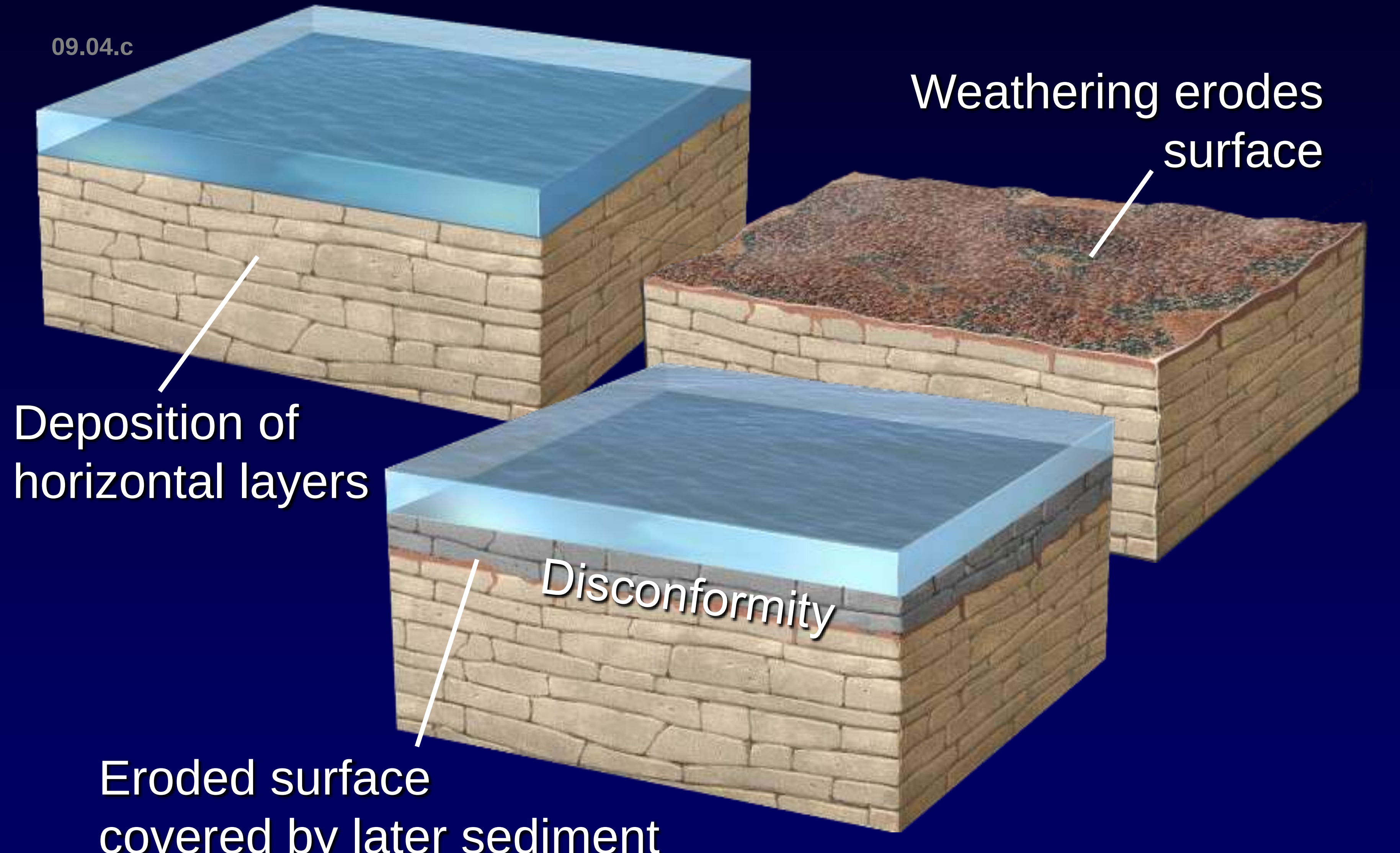
Erosion surface buried by sediment

Observe the nonconformity drawn on this photograph

Disconformity

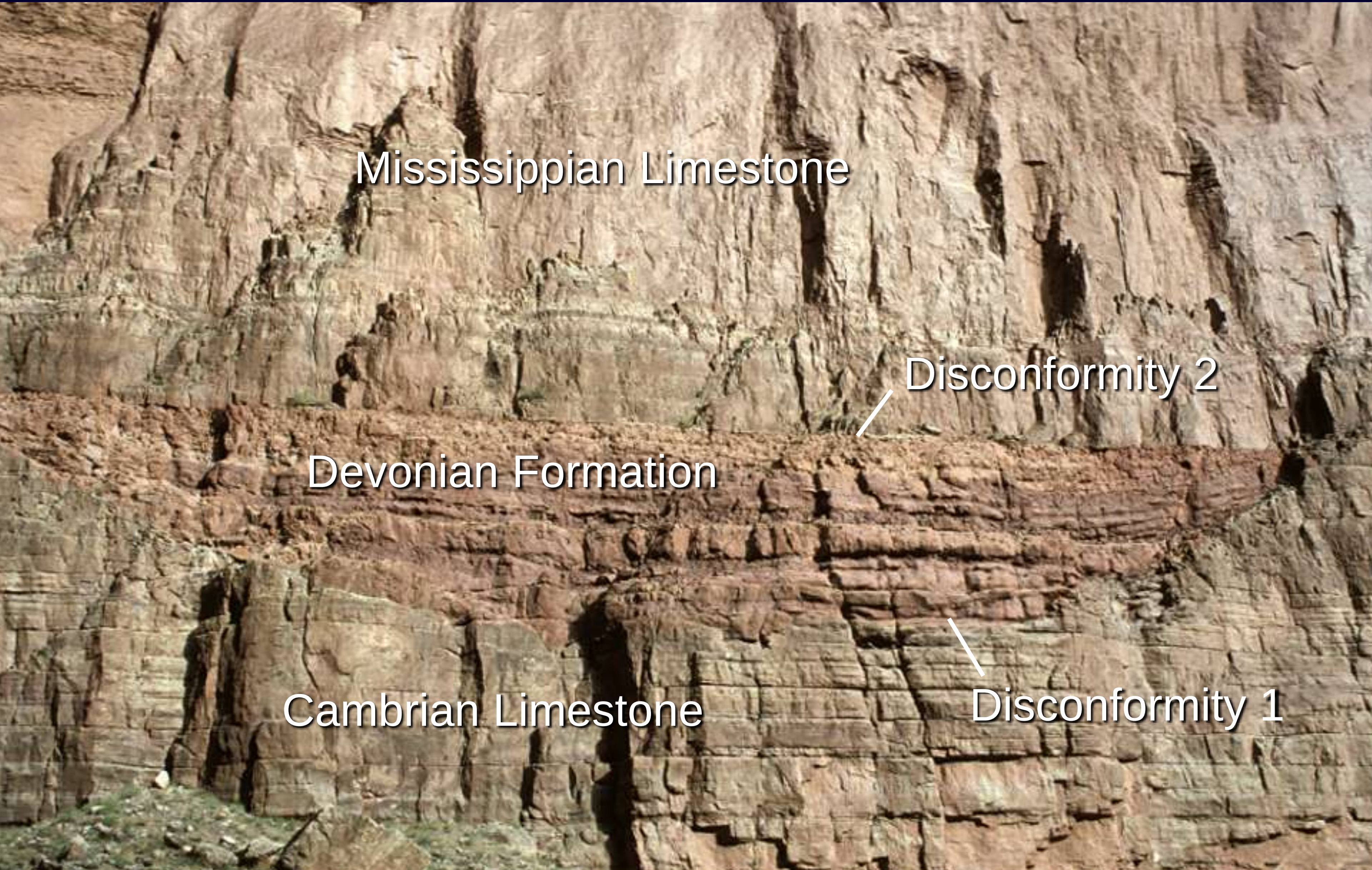
- Parallel layers, missing fossils/time

How Do Disconformities Form?



Observe this photograph and identify two disconformities

09.04.c



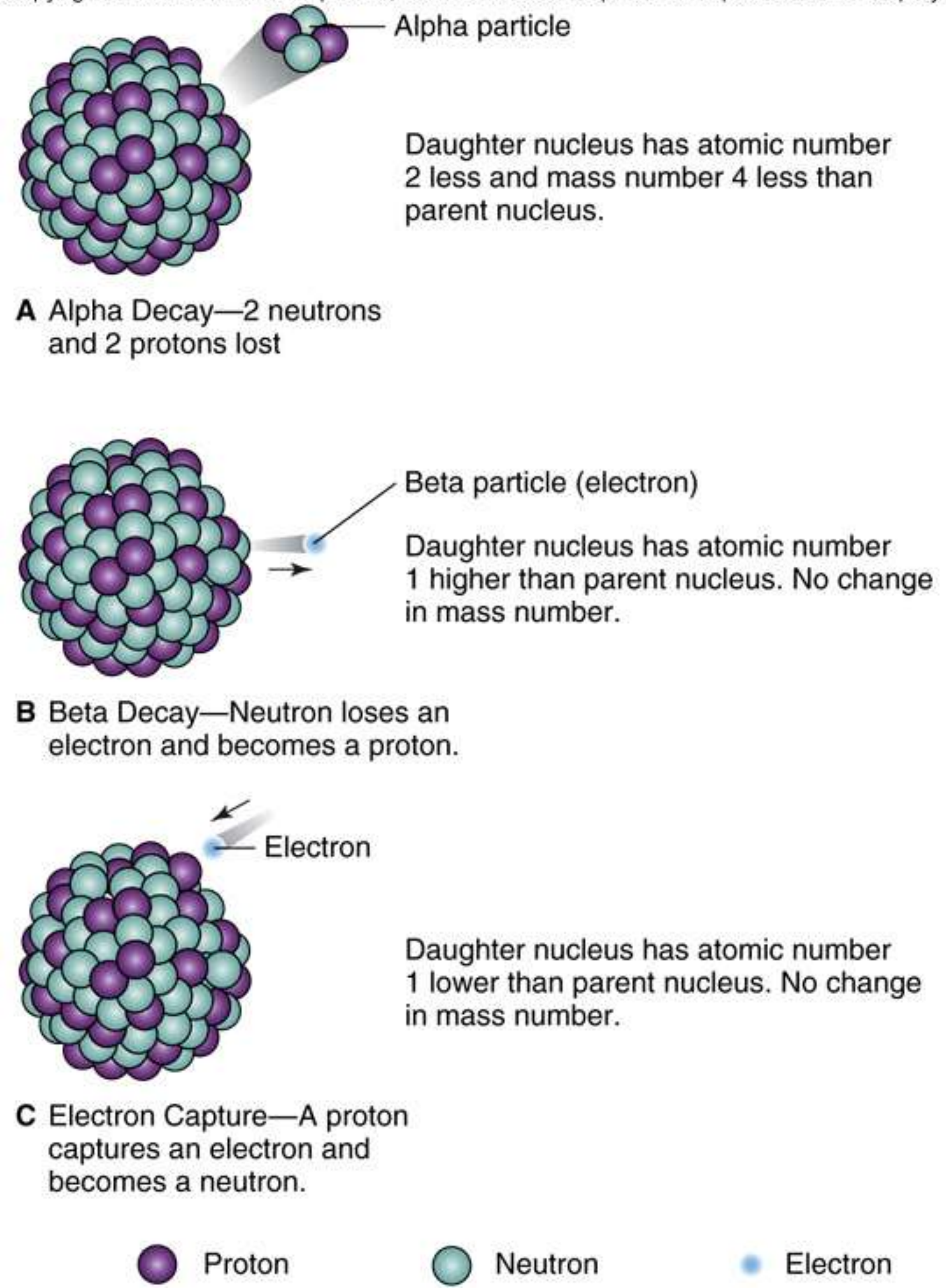
Observe the disconformity in this photograph

09.04.c

Radioactive age dating

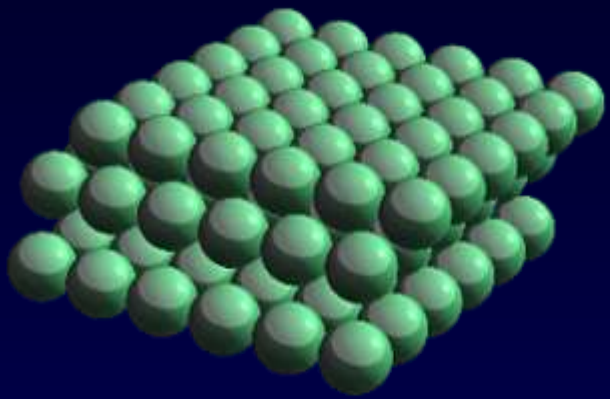
- Unstable elements (a parent such as uranium) decay to more stable elements (a daughter product such as lead) in a known rate
- The proportion of the amount of the daughter product to the amount of the parent element, along with the known (measured) rate of decay allow the age to be calculated

Types of radio-active decay

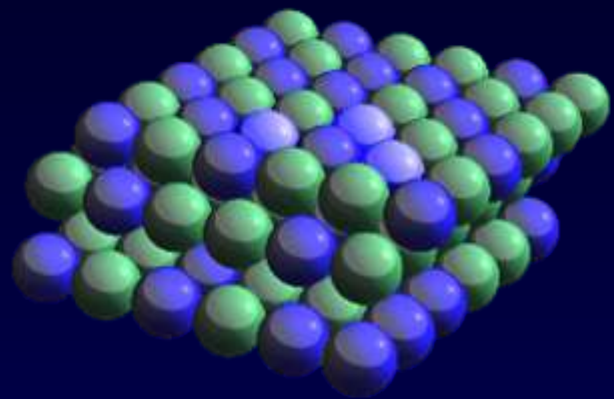


How Does Radioactive Decay Occur?

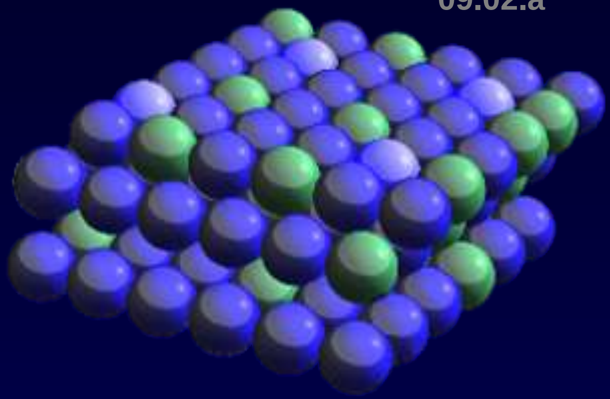
09.02.a



Before decay, unstable parent atoms



Half the parent atoms decayed to daughter atoms (time = half life)

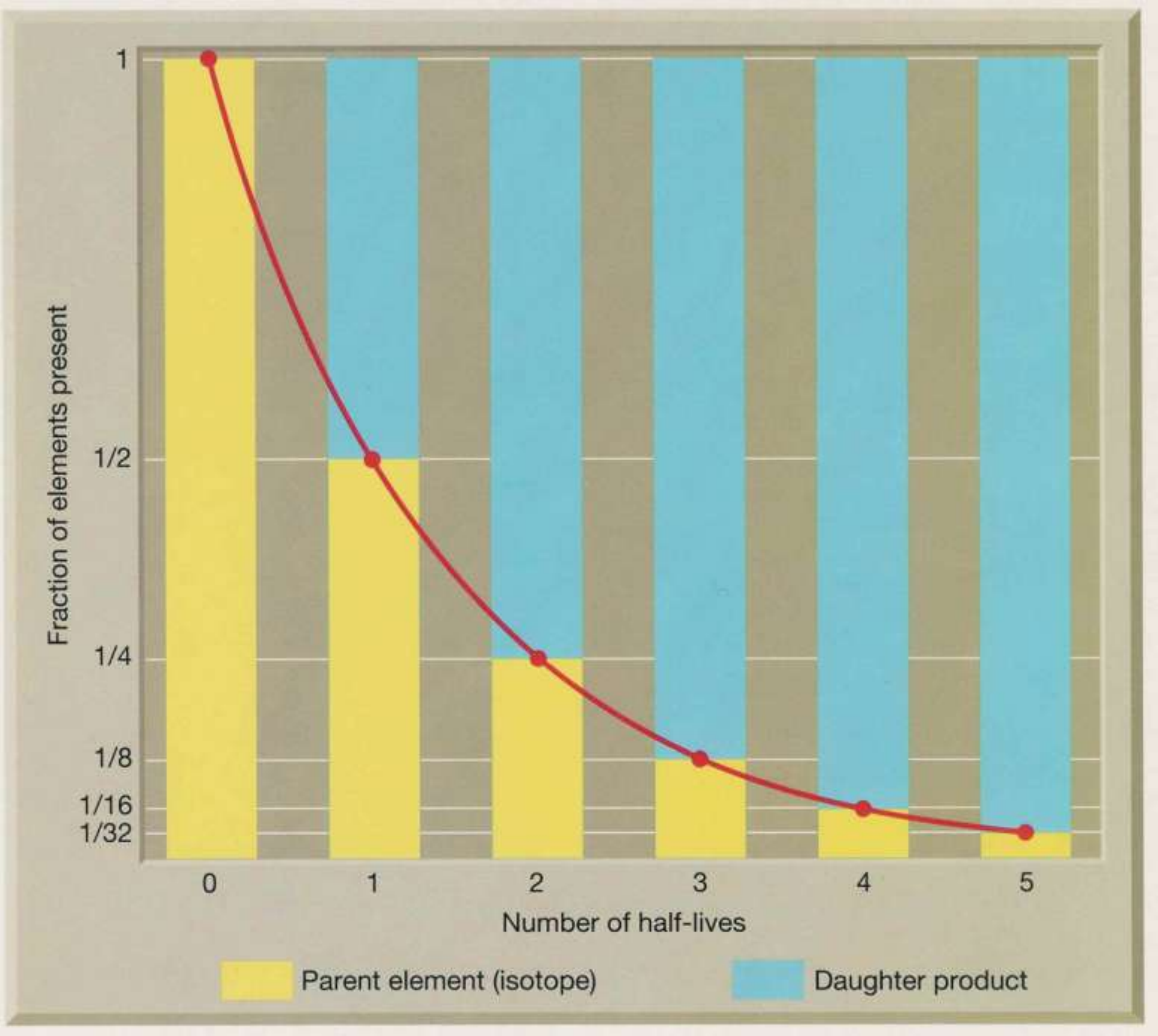


After a second half life, only ¼ parent atoms remain

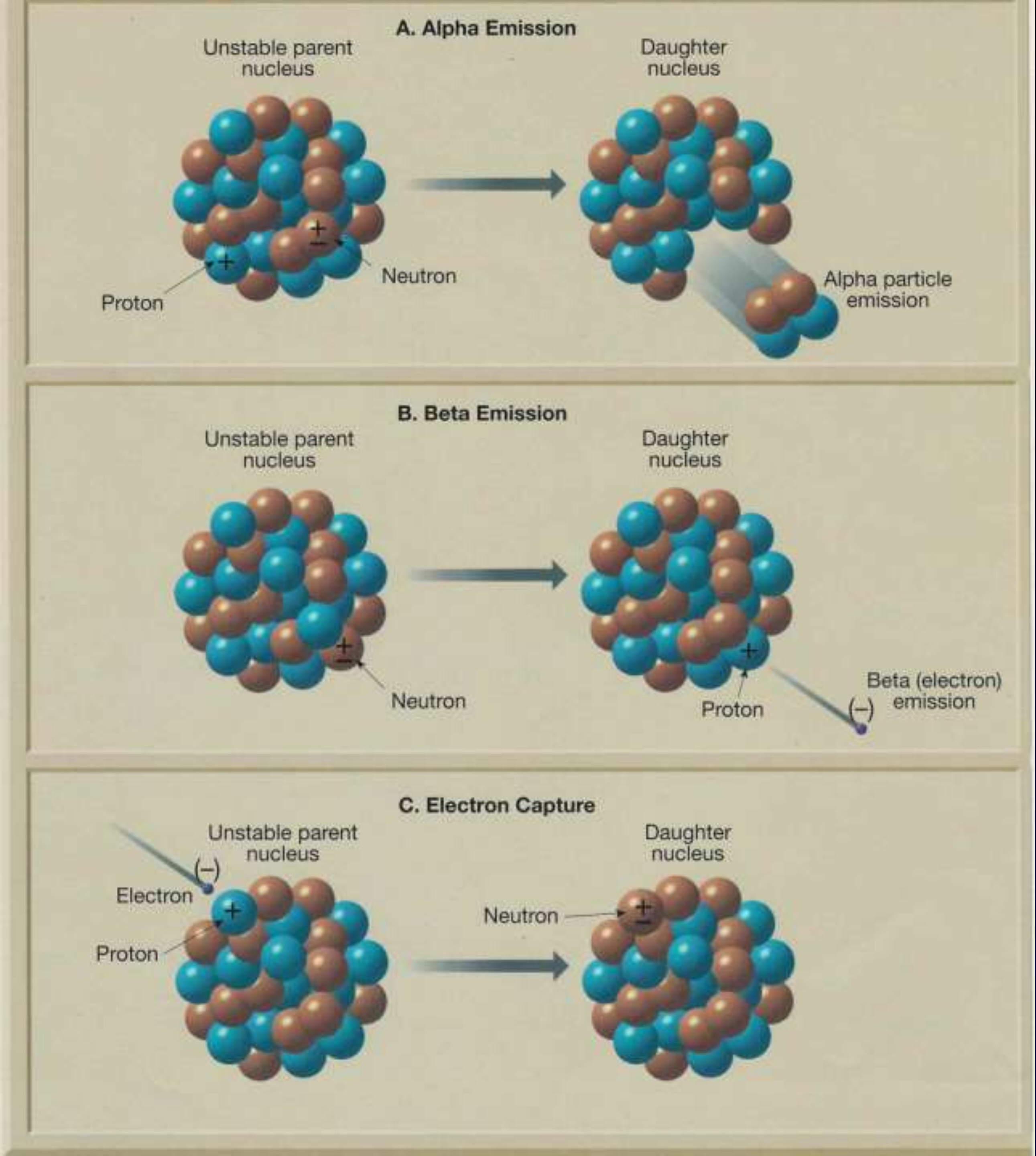
Example for 1000 atoms

	Before Any Decay	After One Half-Life	After Two Half-Lives
Atoms of Parent	1,000	500	250
Atoms of Daughter	0	500	750

Half Life – Radio-active Decay



Alpha, Beta emission



Common nuclides for radioactive dating

TABLE 1-3 Some of the More Useful Nuclides for Radioisotopic Dating

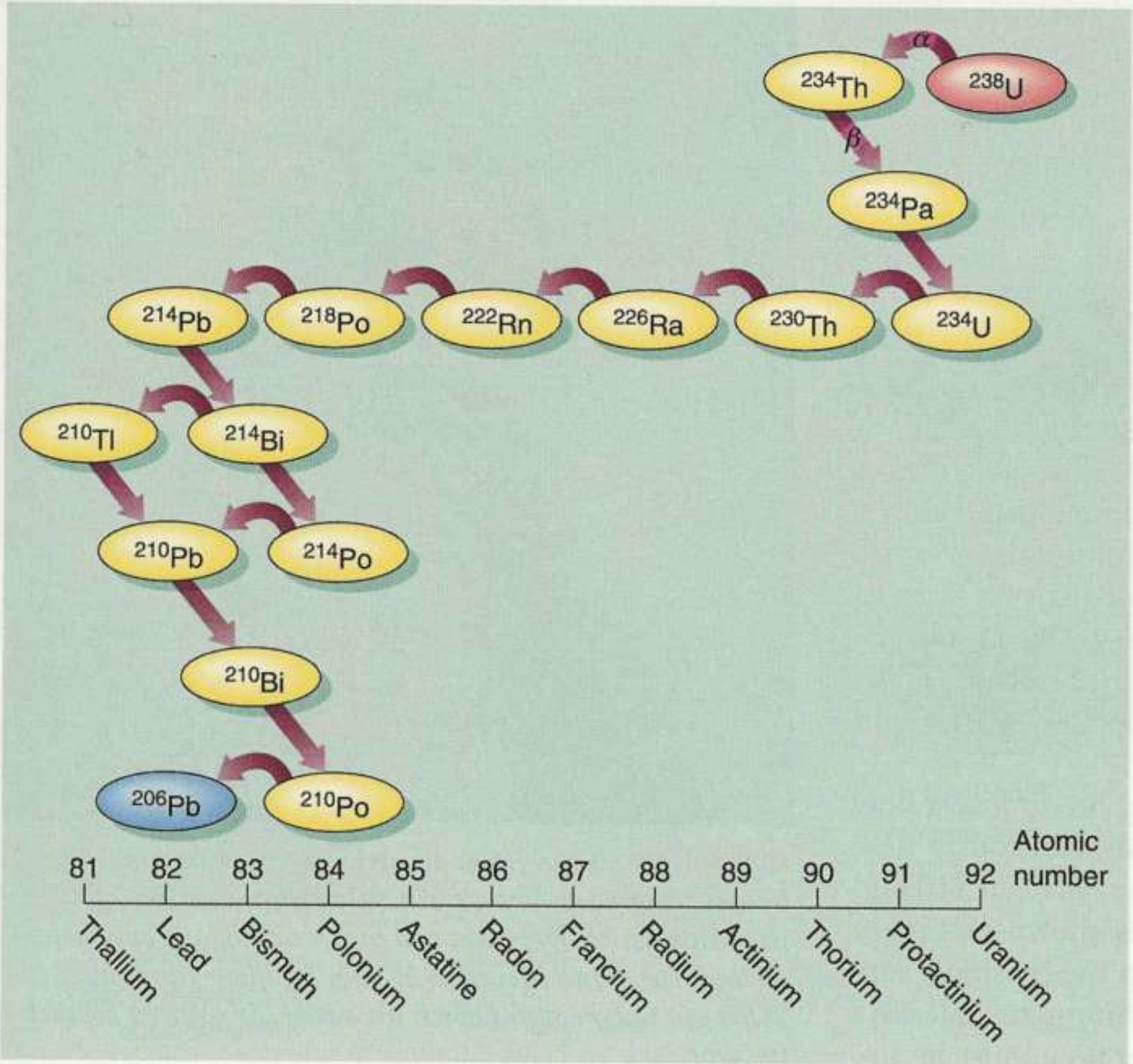
Parent Nuclide*	Half-Life†	Daughter Nuclide	Source Materials
Carbon-14	5730 years	Nitrogen-14	Organic matter
Uranium-238	4.5 billion years	Lead-206	Zircon, uraninite, pitchblende
Uranium-235	704 million years	Lead-207	
Thorium-232	14 billion years	Lead-208	
Rubidium-87	48.8 billion years	Strontium-87	Potassium mica, potassium feldspar, biotite, glauconite, whole metamorphic or igneous rock
Potassium-40	1251 million years (1.251 billion years)	Argon-40 (and calcium-40)‡	Muscovite, biotite, hornblende, whole volcanic rock, glauconite, and potassium feldspar†‡

*_Nuclide_ is a convenient term for any particular atom (recognized by its particular combination of neutrons and protons).

†Half-life data from Steiger, R. H., and Jäger, E. 1977. Subcomission on geochronology: Convention on the use of decay constants in geo- and cosmochronology, _Earth and Planetary Science Letters_ 36:359–362.

‡Although potassium-40 decays to argon-40 and calcium-40, only argon is used in the dating method because most minerals contain considerable calcium-40 even before decay has begun.

Uranium 238 decay to lead 206



Lead - Lead

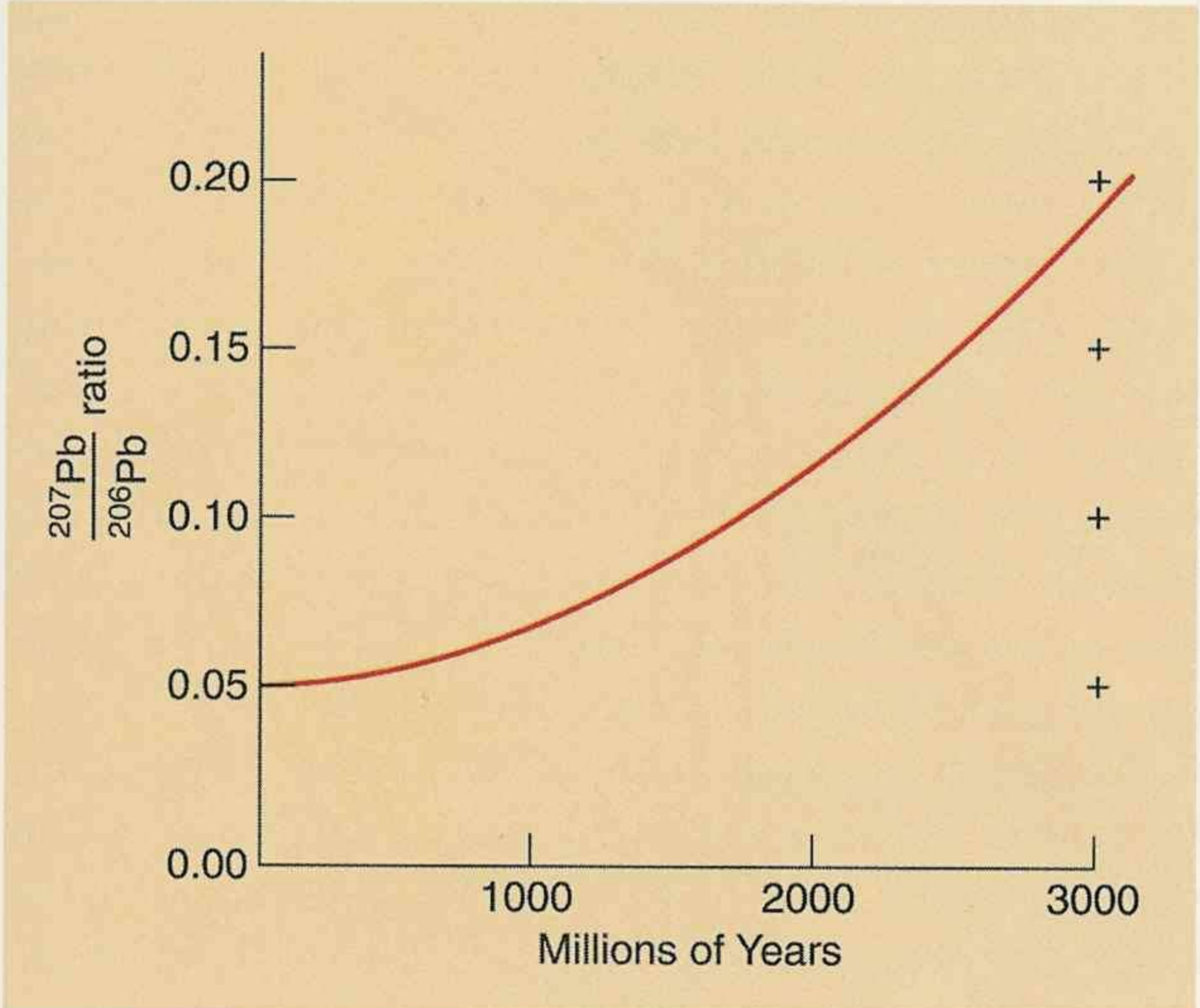


FIGURE 1-26 Graph showing how the ratio of lead-207 to lead-206 can be used as a measure of age.

? *What would be the age of a rock having a $^{207}Pb/^{206}Pb$ ratio of 0.15?*

Commonly used isotopes

Table 8.3 Radioactive Isotopes Commonly Used for Determining Ages of Earth's Materials

Parent Isotope	Half-Life	Daughter Product	Effective Dating Range (years)
K-40 ^{40}K	1.25 billion years	^{40}Ar	100,000–4.6 billion
U-238 ^{238}U	4.5 billion years	^{206}Pb	10 million–4.6 billion
U-235 ^{235}U	713 million years	^{207}Pb	10 million–4.6 billion
Th-232 ^{232}Th	14.1 billion years	^{208}Pb	10 million–4.6 billion
Rb-87 ^{87}Rb	49 billion years	^{87}Sr	10 million–4.6 billion
C-14 ^{14}C	5,730 years	^{14}N	100–40,000

Rubidium - Strontium

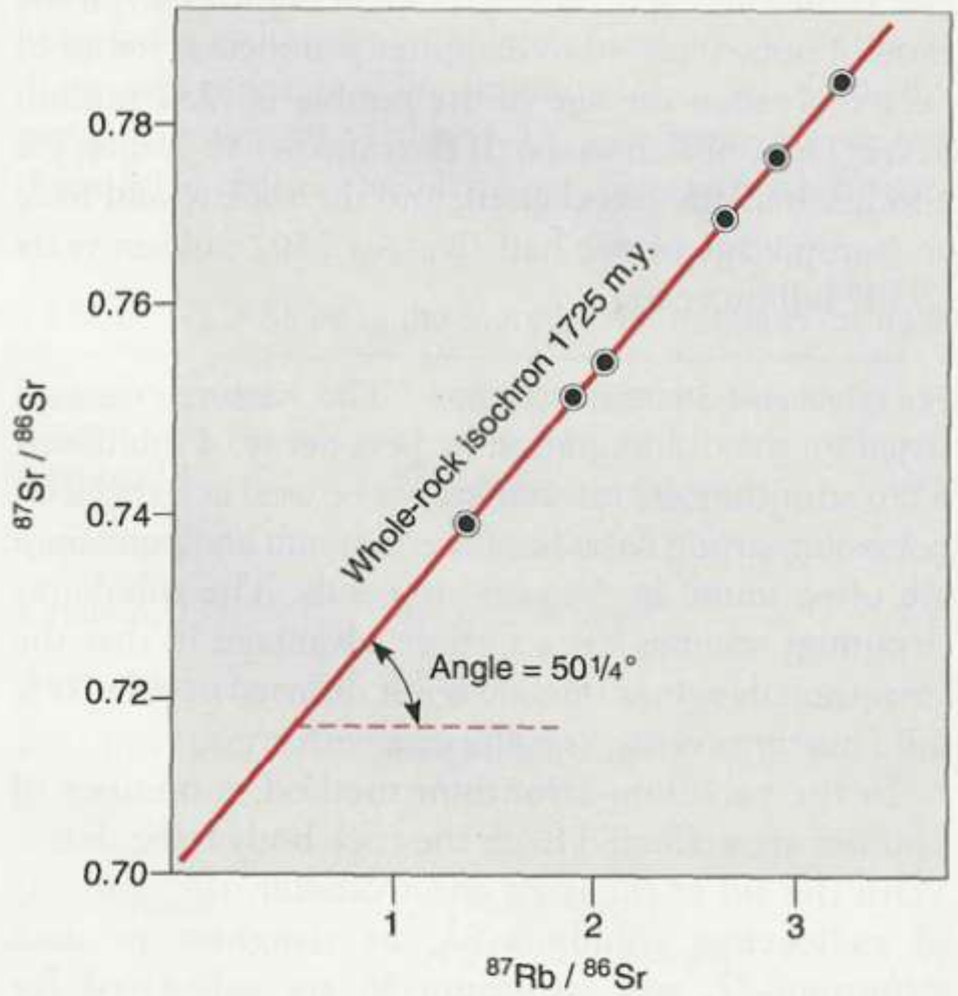


FIGURE 1-28 Whole-rock rubidium-strontium isochron for a set of samples of a Precambrian granite body exposed near Sudbury, Ontario. (*Modified from Krogh, T. E. et al. 1968. Carnegie Institute Washington Year Book 66:530.*)

Carbon 14

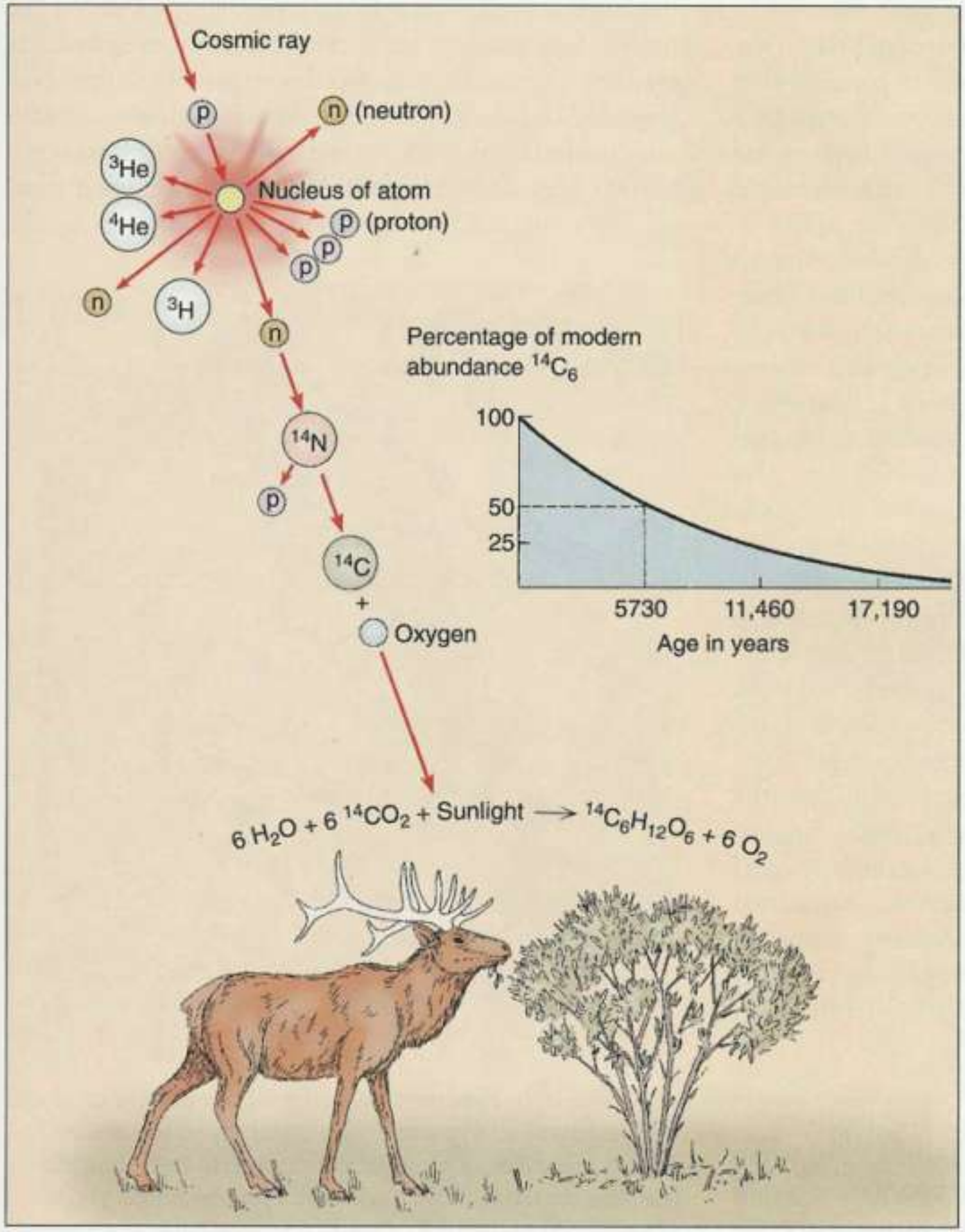
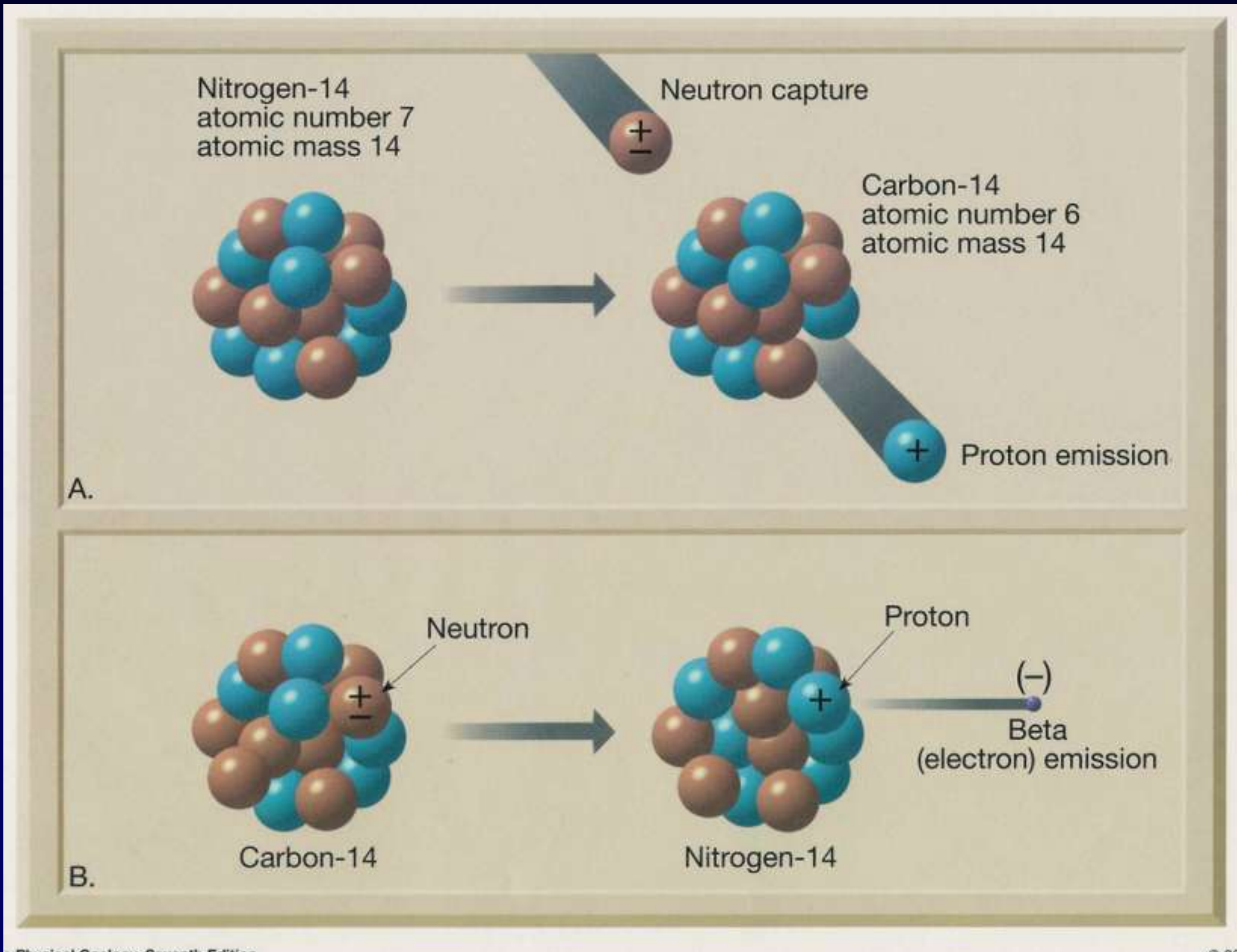
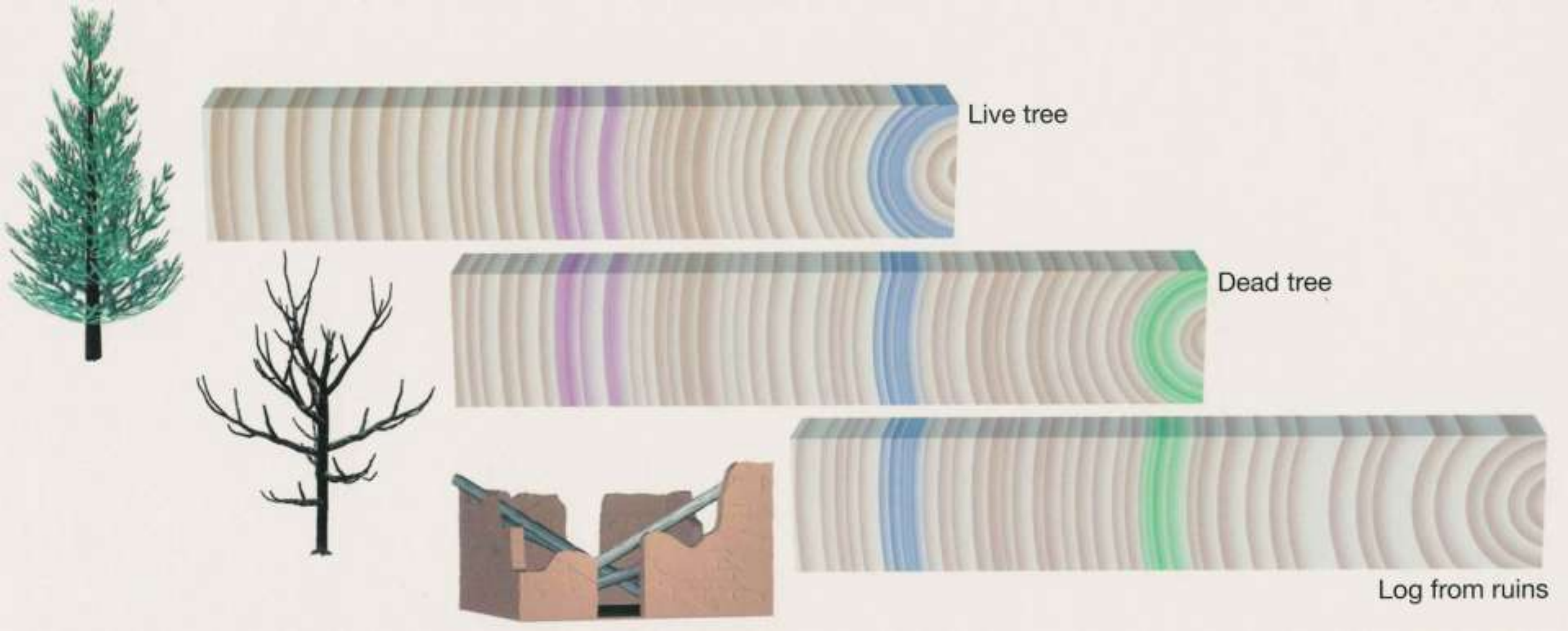


FIGURE 1-28 Carbon-14 is formed from nitrogen in the atmosphere. It combines with oxygen to form radioactive carbon dioxide and is then incorporated into all living things.

Nitrogen 14 to Carbon 14



Tree ring dating



What Can Isotopic Ages Tell Us?

09.02.c

Age of eruption

Age of solidification

Age of meta. event

When rock cooled

Age of source of sediment

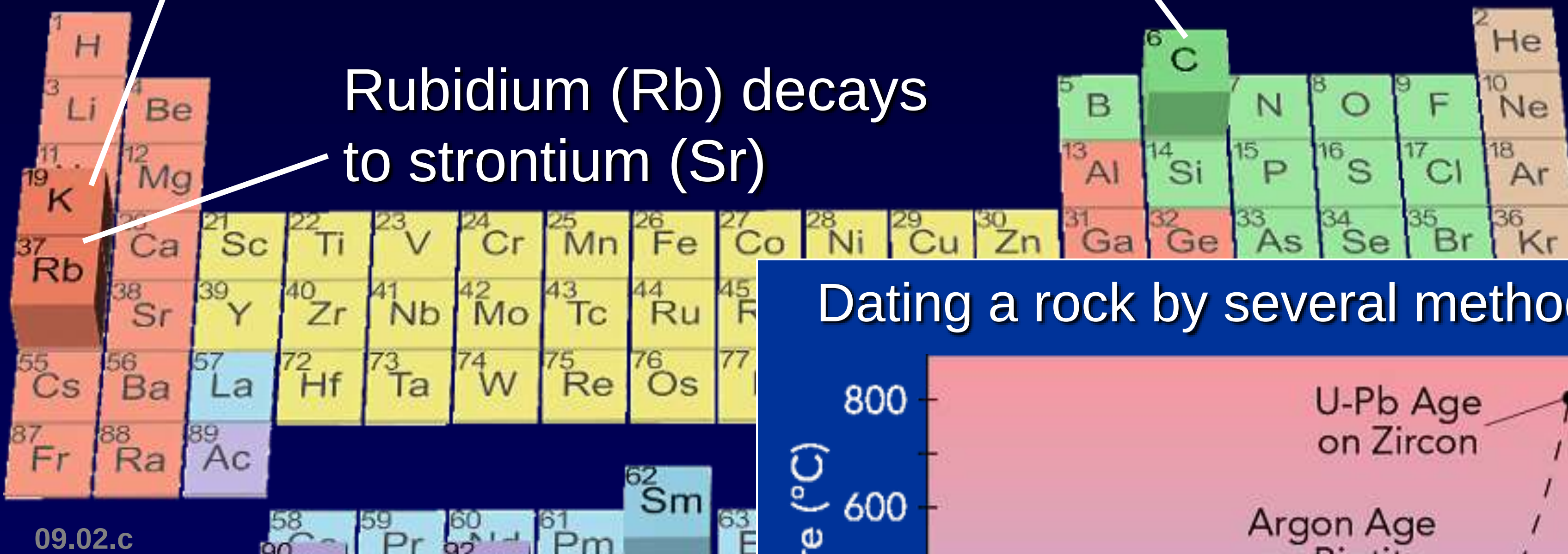
Age of recent sediment

Common Radioactive Decay Series

Potassium (K) decays to argon (Ar)

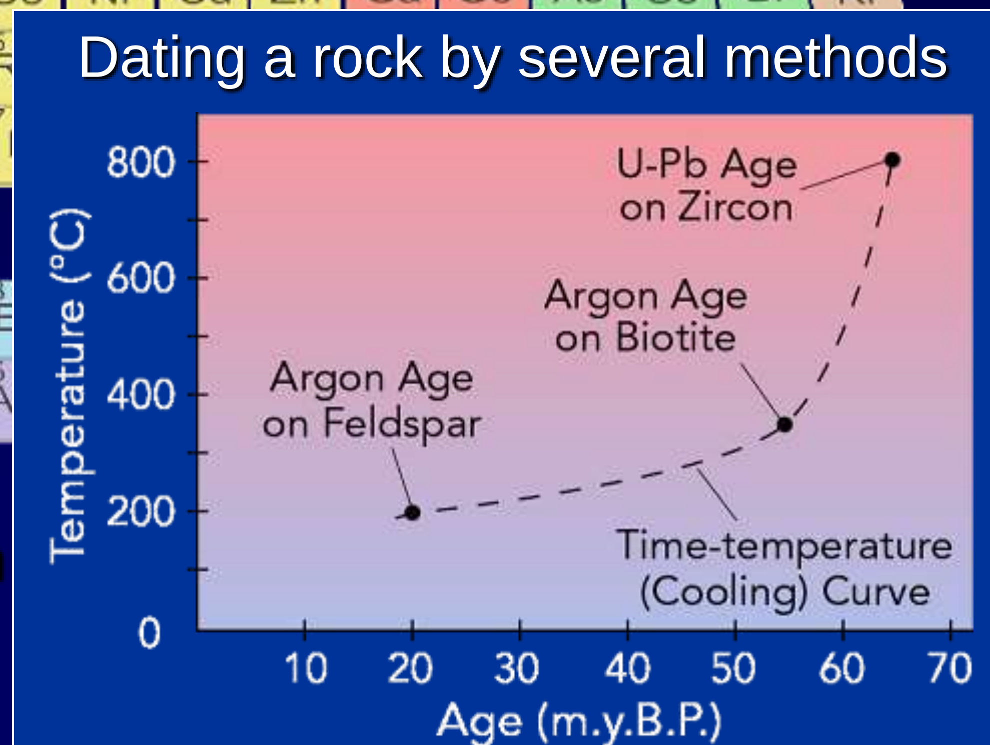
Carbon-14 (C) decays to nitrogen (N)

Rubidium (Rb) decays to strontium (Sr)



09.02.c

Thorium (Th) and uranium (U) decay to isotopes of lead (Pb)

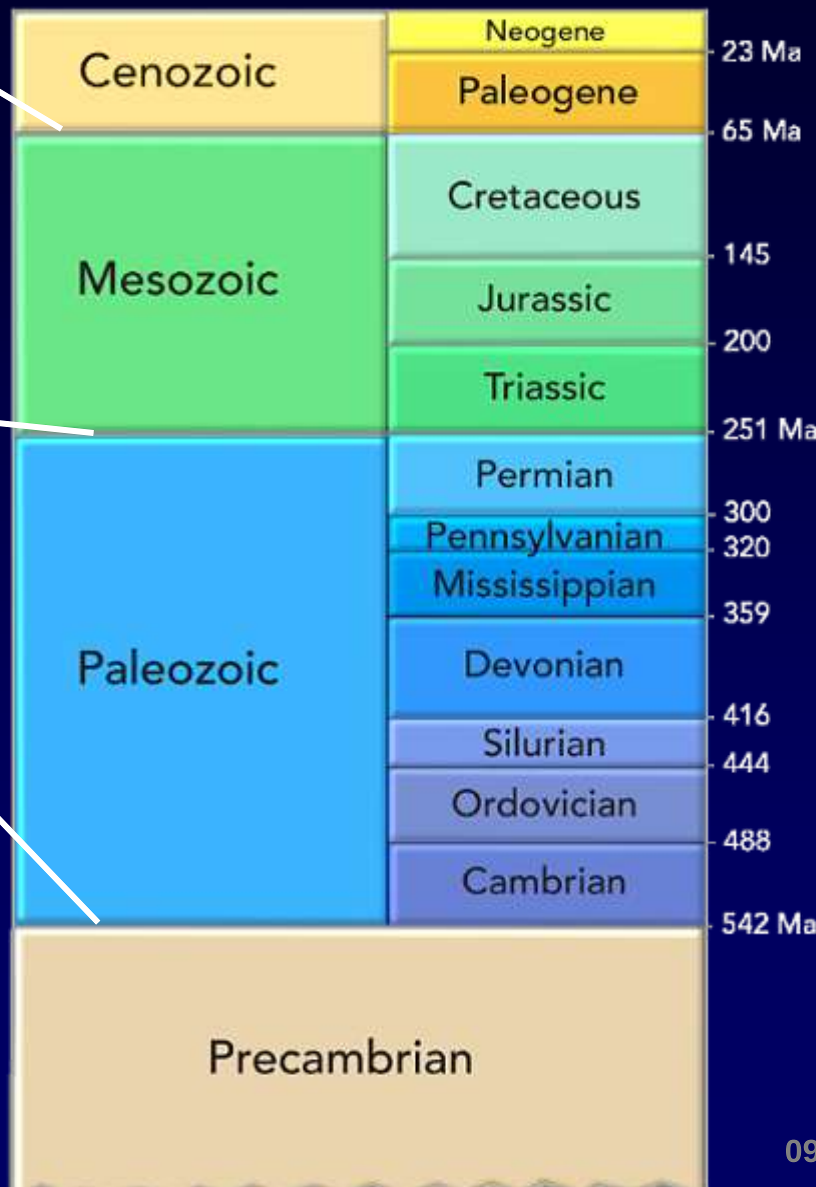


Geologic Time Scale

Boundary based on mass extinction (dinos and others)

Boundary based on major mass extinction called the *Great Dying*

Boundary based on widespread appearance of hard-shelled organisms

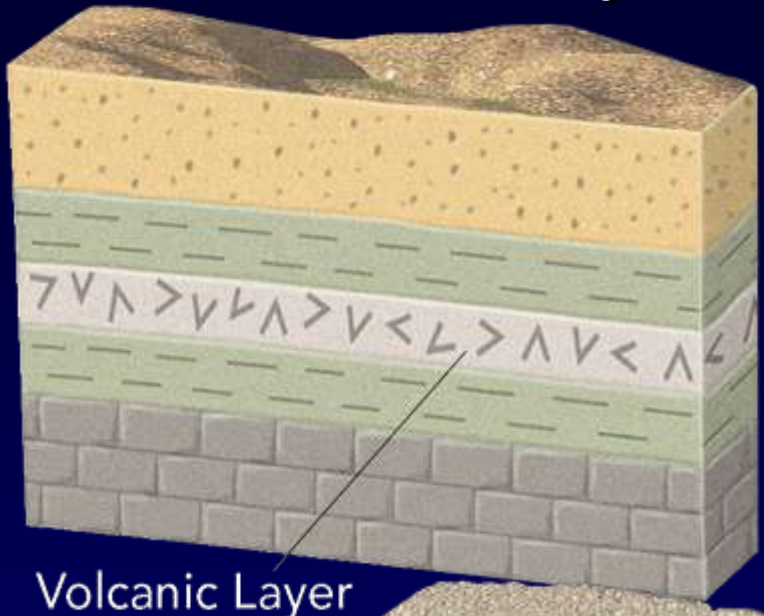


Older subdivisions of Cenozoic

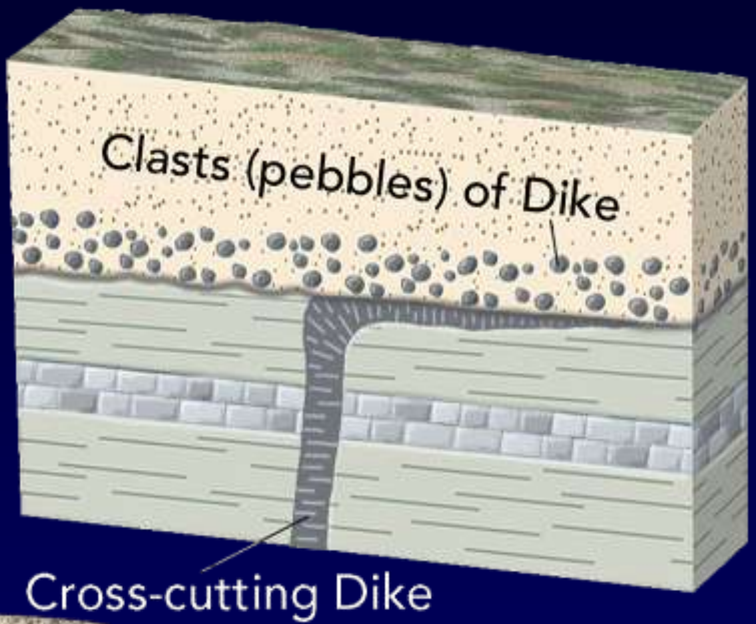
09.08.a1

Assigning Numeric Ages to Timescale

Date a volcanic layer



Date a dike or clasts

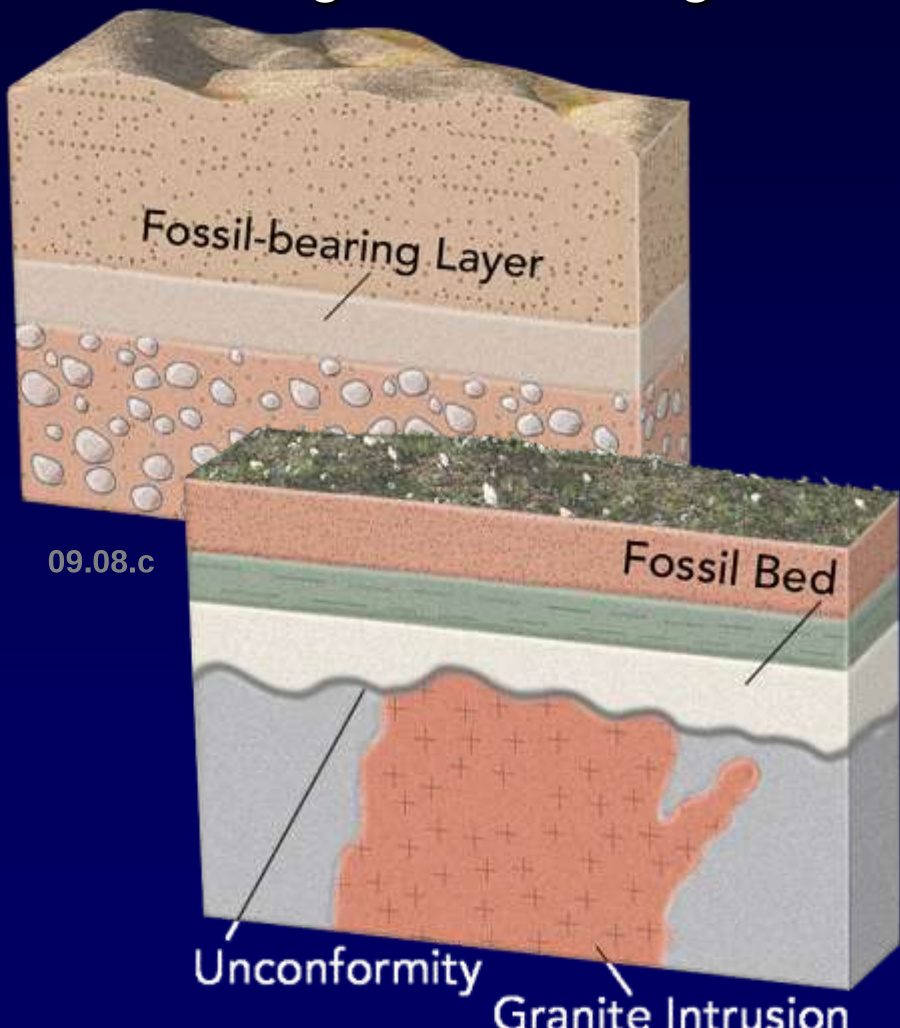


09.08.b

Bracket fossil-bearing bed by dating volcanic units

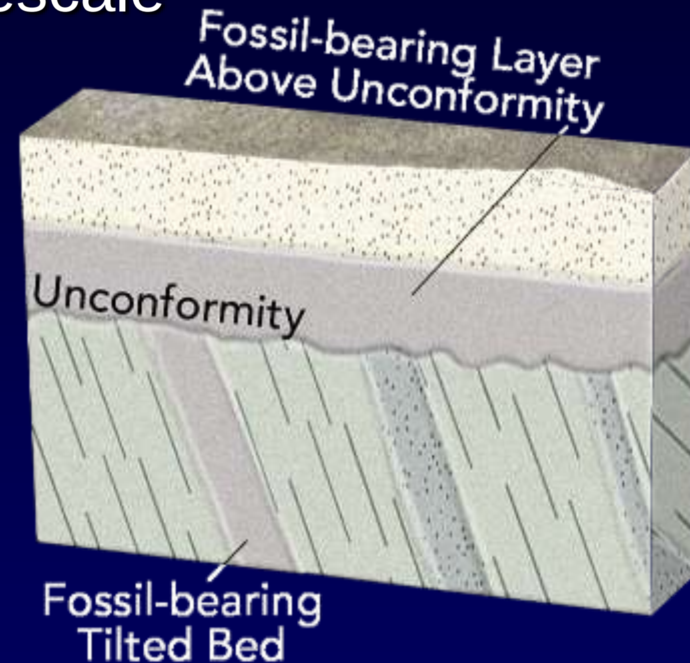
Using Timescale to Assign Numeric Ages

Use fossils and timescale to assign numeric age



09.08.c

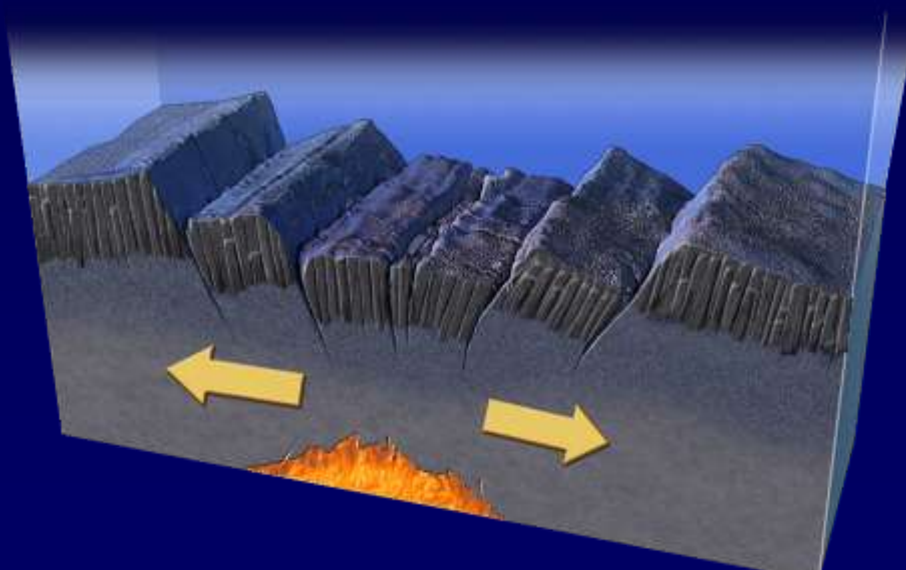
Bracket using fossil ages from timescale



Bracket age using fossil and numeric ages

Evidence that Earth's History is Not Short

09.09.b



Current rates of plate motion

Where Age of Earth Comes From

Age of meteorites

4.55 billion

Dated Moon rocks

4.5 billion

Oldest dates on Earth rocks

3.9 to 4.0 b.y. (rock) to 4.3 b.y. (grains)

Data from astronomy on age of Solar System and Universe

Precambrian Life

Cambrian Explosion

Life in the Paleozoic

Early Paleozoic

Middle Paleozoic

Late Paleozoic

09.10.c

Life in the Mesozoic

Early Mesozoic: Triassic

Middle Mesozoic: Jurassic

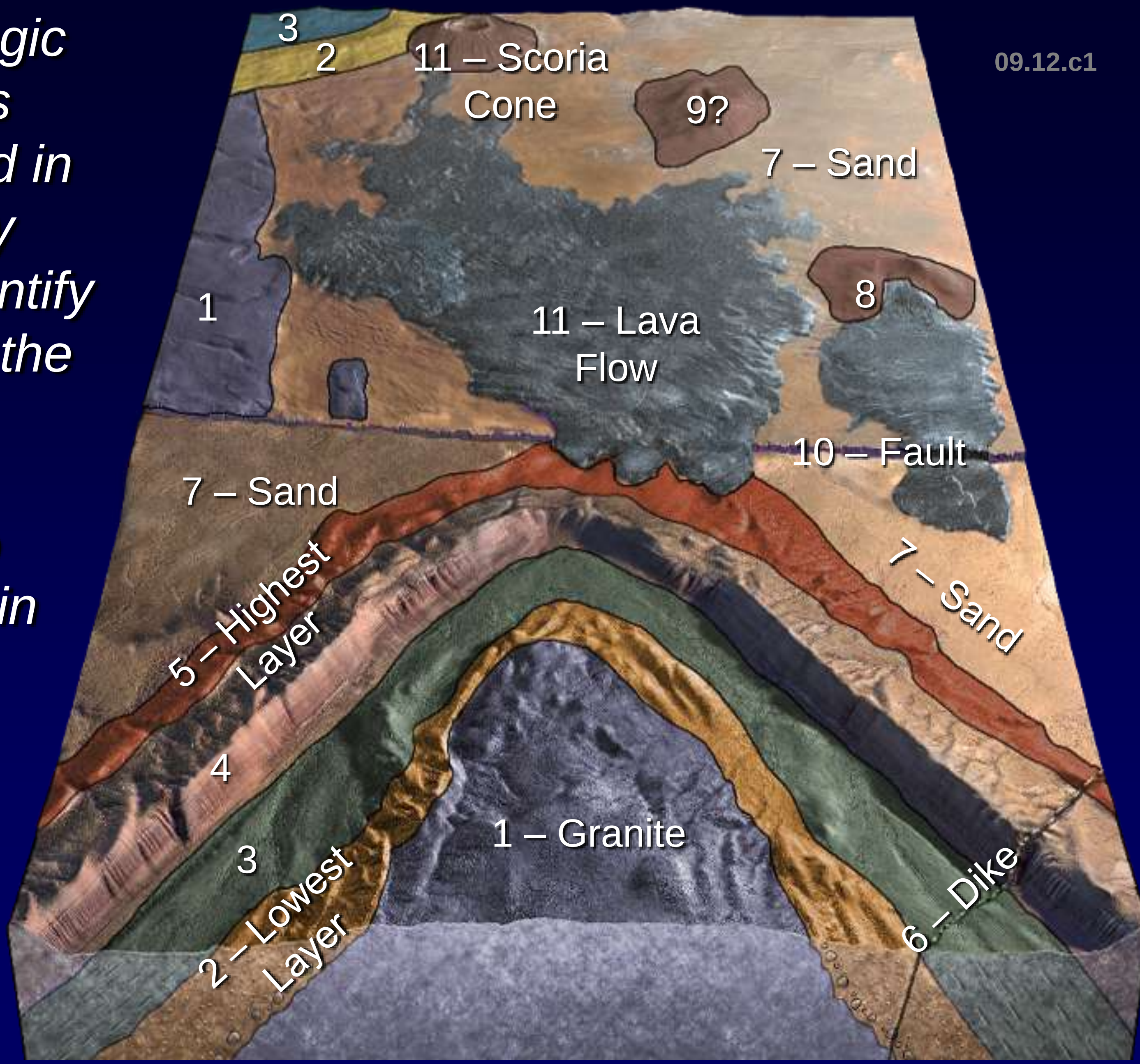
Late Mesozoic: Cretaceous

Life in the Cenozoic

Early Cenozoic

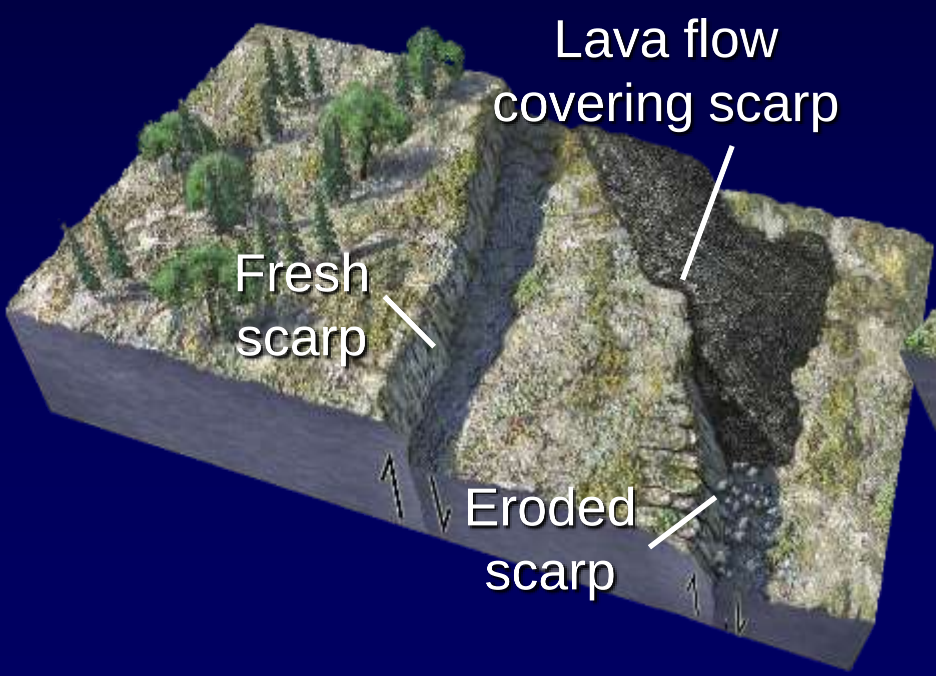
Late Cenozoic

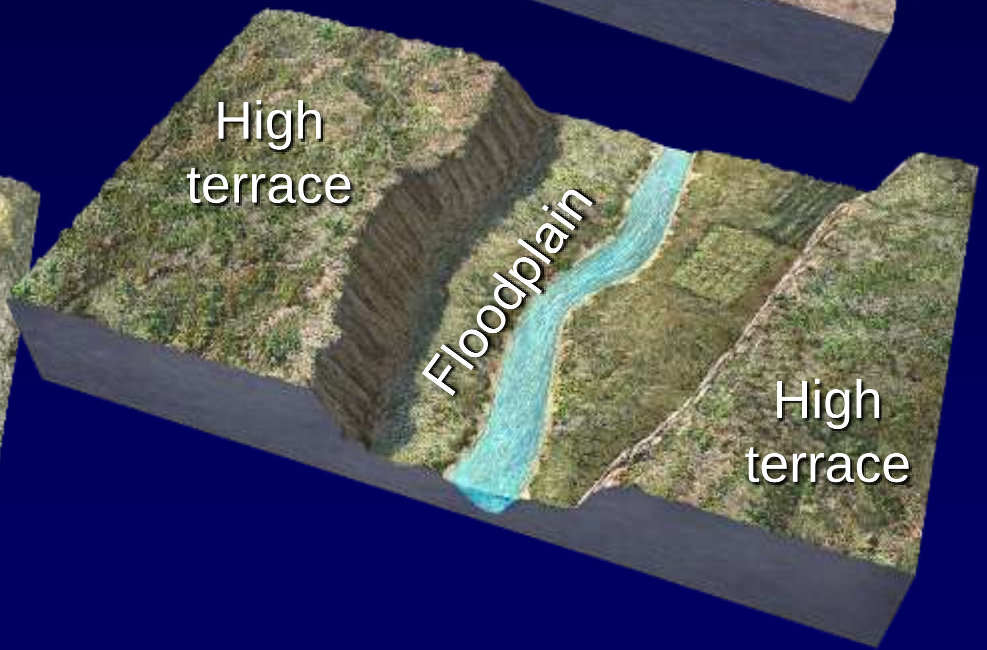
On this geologic map, features are numbered in the order they occurred. Identify reasons why the units and features are interpreted to have formed in this relative order.



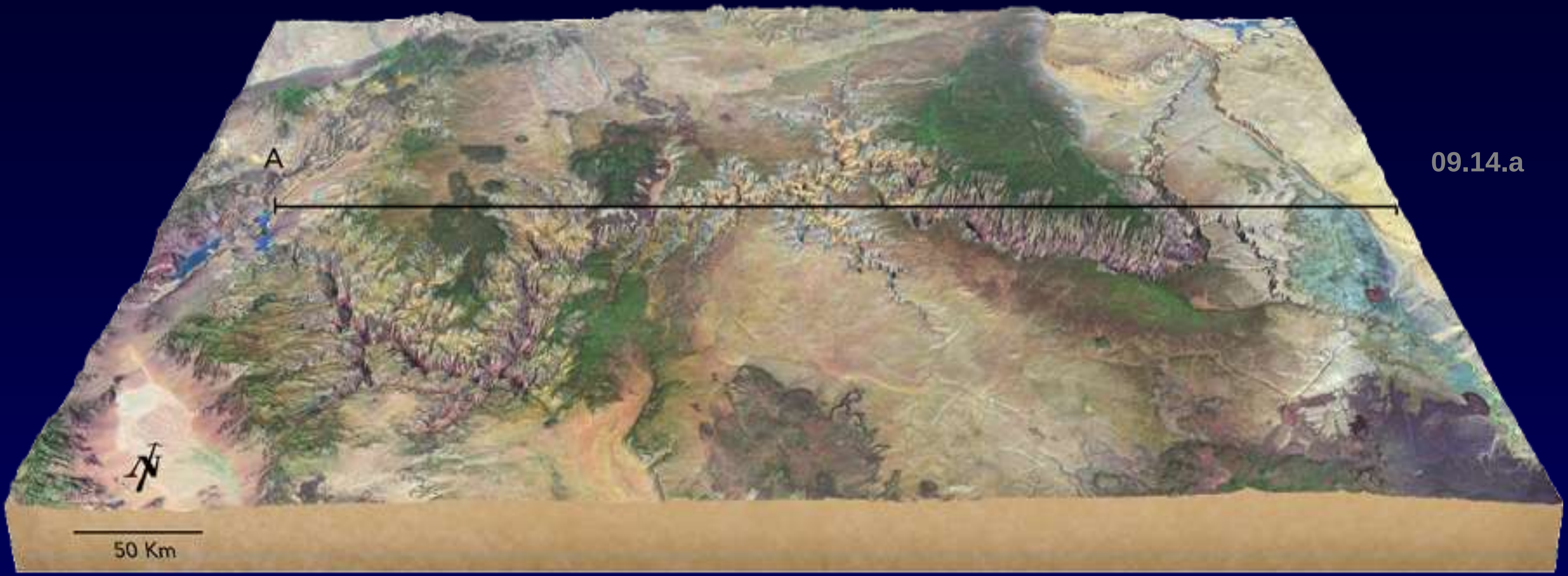
09.12.c1

Observe each figure and think about how the information is important in determining potential for geologic hazards





Observe this satellite image of the Grand Canyon



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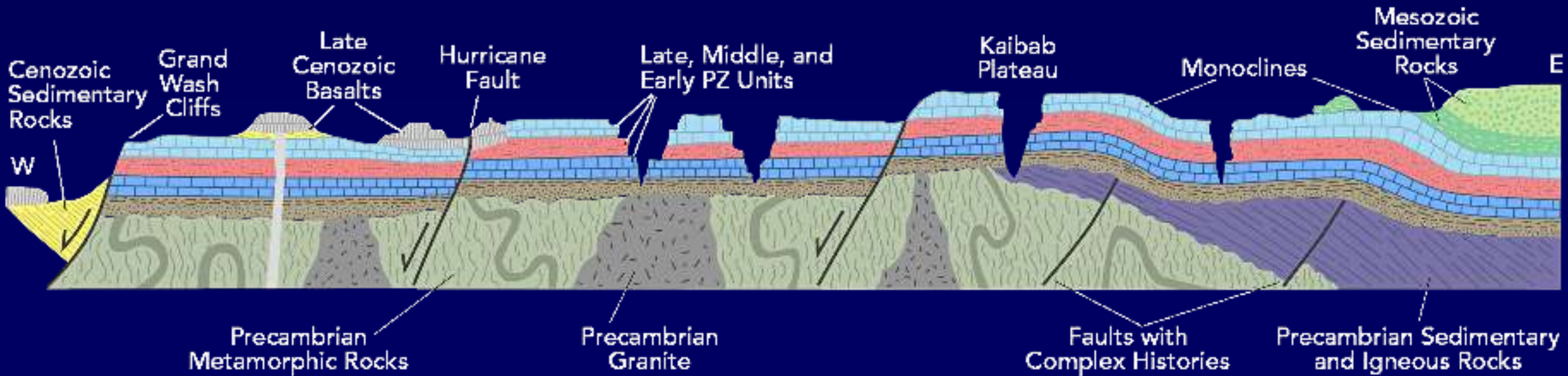
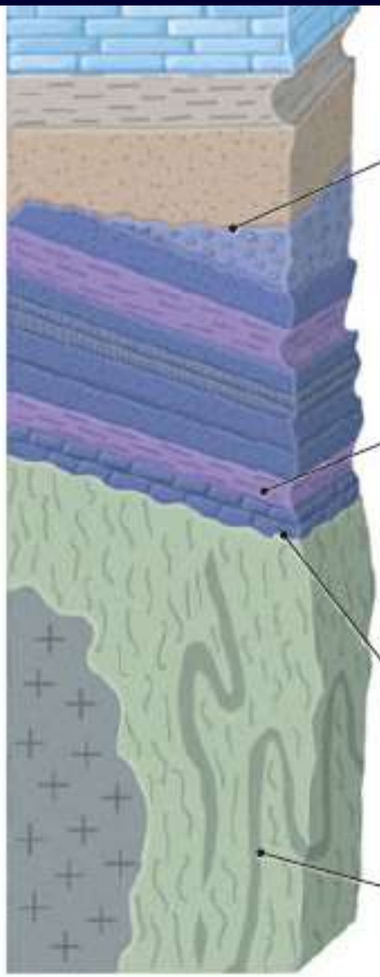


3D

Geologic History of Grand Canyon, Part 1



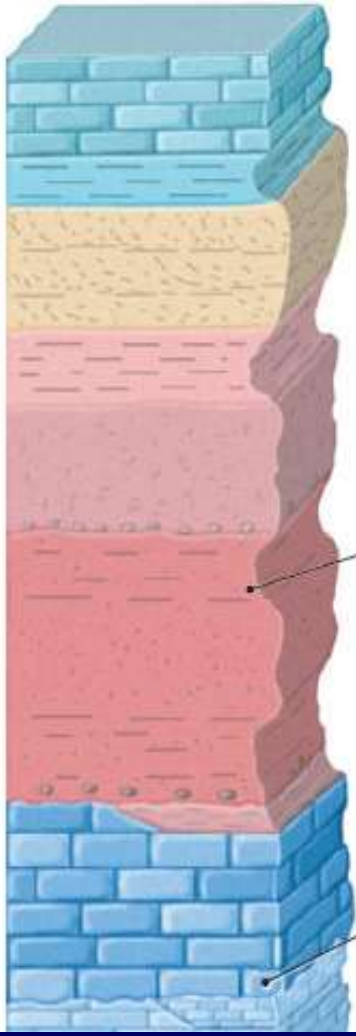
4. *Tilting and Upper Unconformity*—Layers in the Late Precambrian rocks were gently to moderately tilted and then beveled by erosion. This produced the *upper unconformity*. As this unconformity is followed west, it truncates the *lower unconformity* beneath the Kaibab Plateau (see the cross section A–B). This combined unconformity represents even more missing time (from 1.7 billion years to 540 million years, or more than 1.1 billion years); it is appropriately called the *Great Unconformity* and can be followed eastward to the Great Lakes region.

3. *Late Precambrian Rocks and Lower Unconformity*—In the Late Precambrian, sedimentary and volcanic rocks were deposited in horizontal layers across the upturned basement layers. This formed the *lower unconformity*. The lower parts of these late Precambrian rocks are dated by several isotopic methods at 1.1 billion years. Since the underlying basement rocks are 1.7 billion years, the lower unconformity represents 600 million years of time not recorded by any rocks!

2. *Uplift and Erosion of the Basement*—After the metamorphism, the basement rocks cooled as they were uplifted and eroded over a period that lasted for hundreds of millions of years. Erosion beveled across the steep metamorphic layers.

1. *Basement Rocks*—Metamorphic and plutonic rocks in the bottom of the canyon represent the oldest events. They were formed, metamorphosed, and deformed to near-vertical orientations, all between 1.76 and 1.70 billion years ago.

Geologic History of Grand Canyon, Part 2



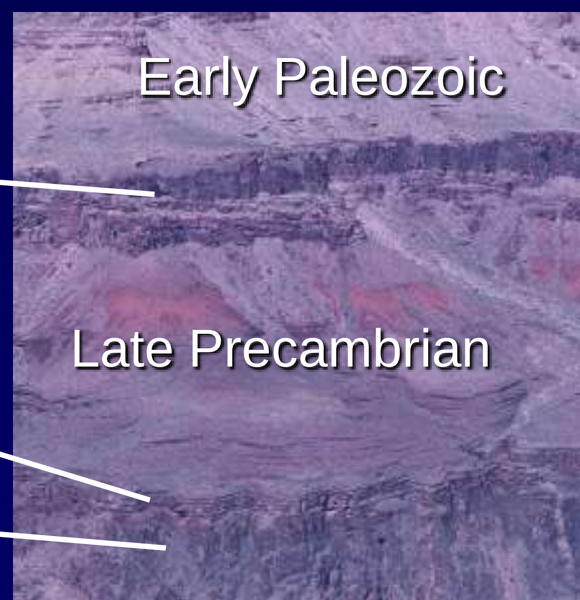
The sequence of events in the Grand Canyon has been reconstructed using relative dating, fossils, and many different isotopic dating methods. The geologic history resulting from these studies is summarized below, which should be read from bottom to top (oldest to youngest).

7. *Deformation, Uplift, and Erosion*—The Paleozoic strata largely have escaped deformation and remain nearly flat, except near a few faults and folds. The monoclines are bracketed, using relative-dating methods, to between 80 and 40 million years ago. The region was uplifted some at this same time, but the modern canyon was not carved until much later, mostly within the last 5 million years.

6. *Deposition of Late Paleozoic Layers*—Overlying sedimentary layers (shown in red, pink, tan, and blue-green) record a wide range of environments, including shallow marine, shorelines, rivers, and a dune-covered desert. These rocks are dated with marine and nonmarine fossils as late Paleozoic (Pennsylvanian and Permian). Disconformities separate some of the formations and represent time when the region was above sea level.

5. *Deposition of Early and Middle Paleozoic Units*—After erosion carved the upper unconformity, seas covered the land and deposited sandstone, shale, and limestone (shown in brown and blue). These deposits are dated by trilobites and other fossils as early and middle Paleozoic (Cambrian, Devonian, and Mississippian). Later, the seas left and in several instances formed disconformities within the limestones.

Observe this stratigraphic section and match the units and unconformities with the sections in the photographs



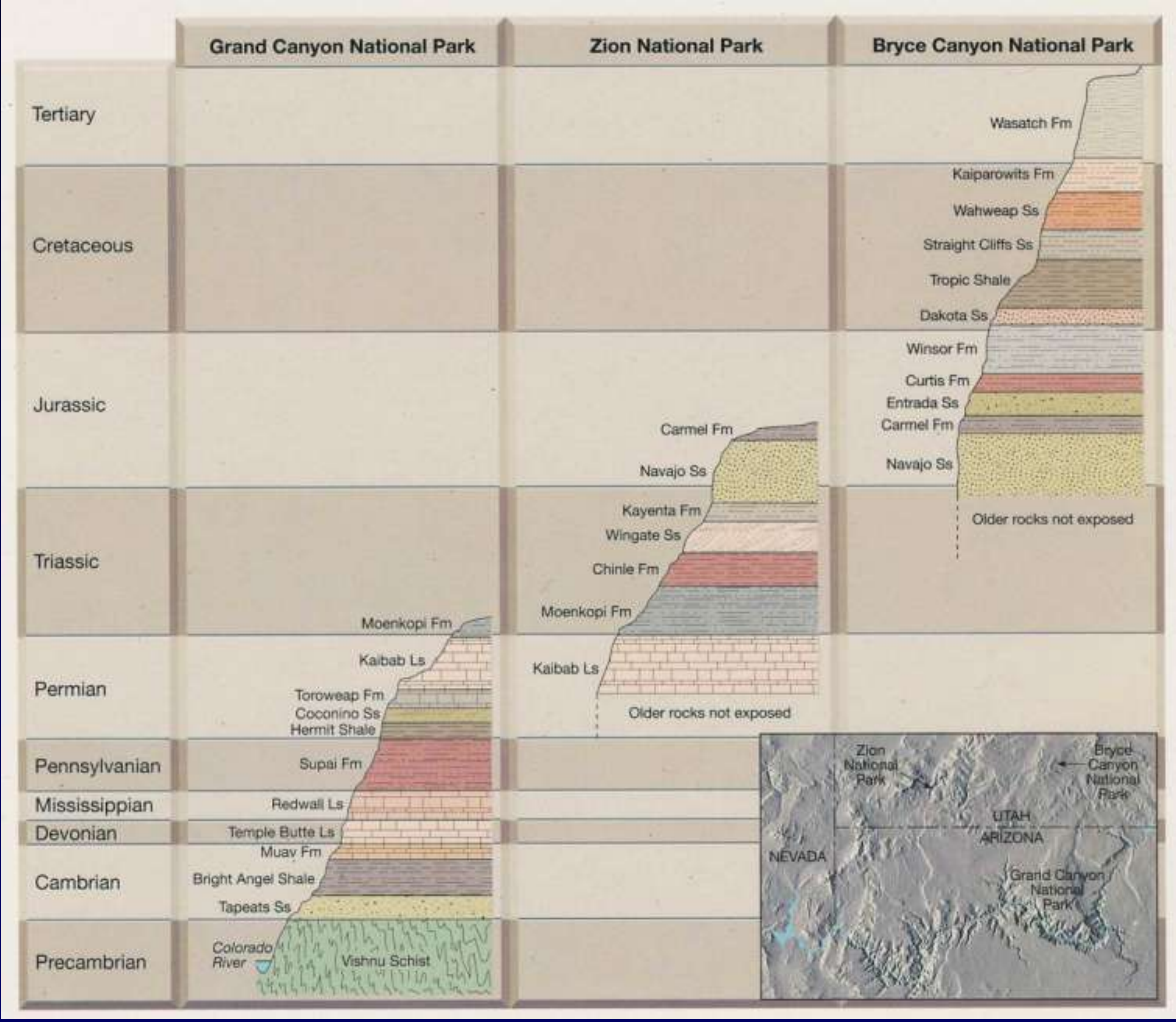
Upper unconformity

Lower unconformity

Precambrian basement

09.14.a

Grand Canyon to Zion to Bryce

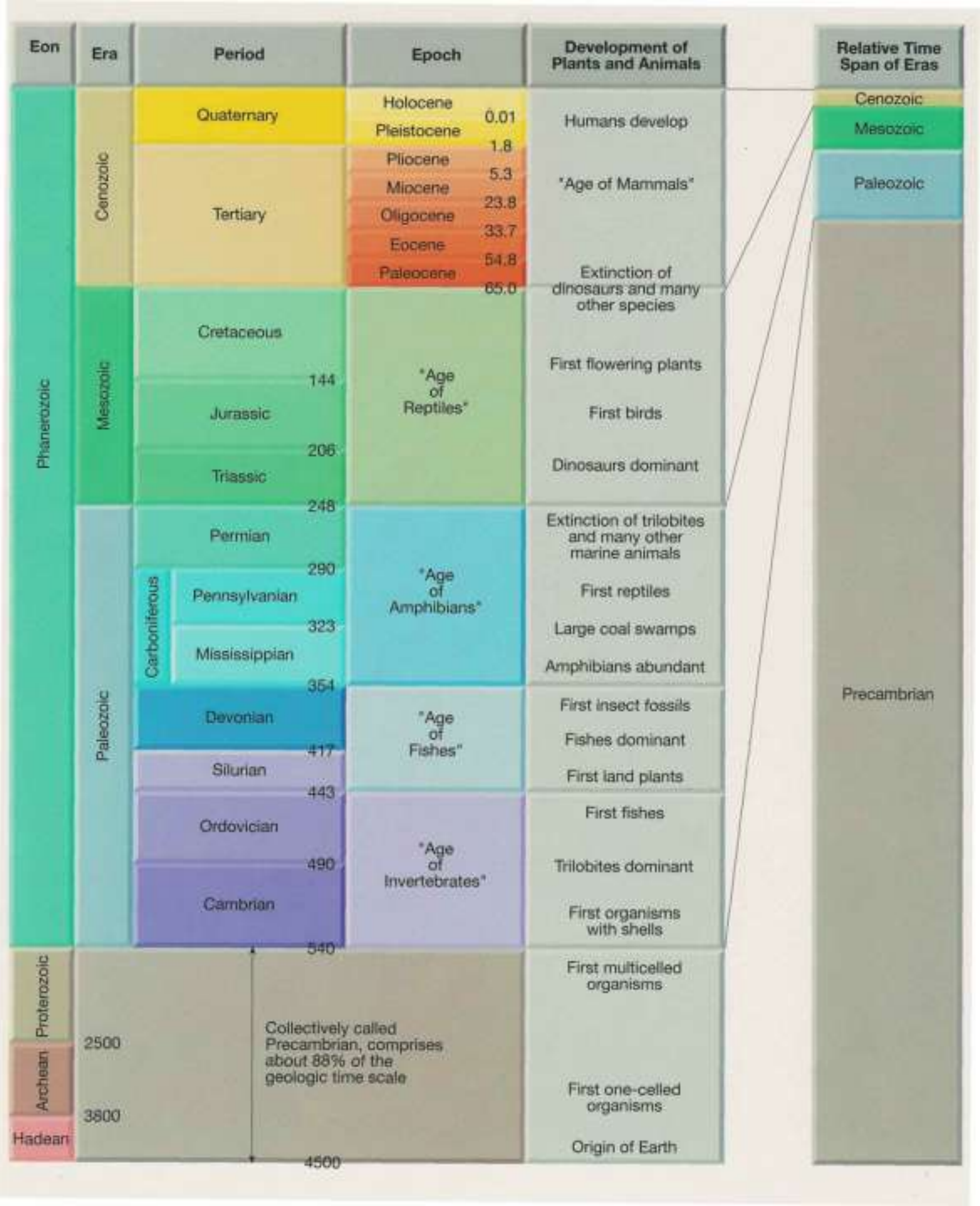


Cambrian on PC Unkar Group

Angular Unconformity: Grand Canyon, Tapeats on Grand Canyon Group

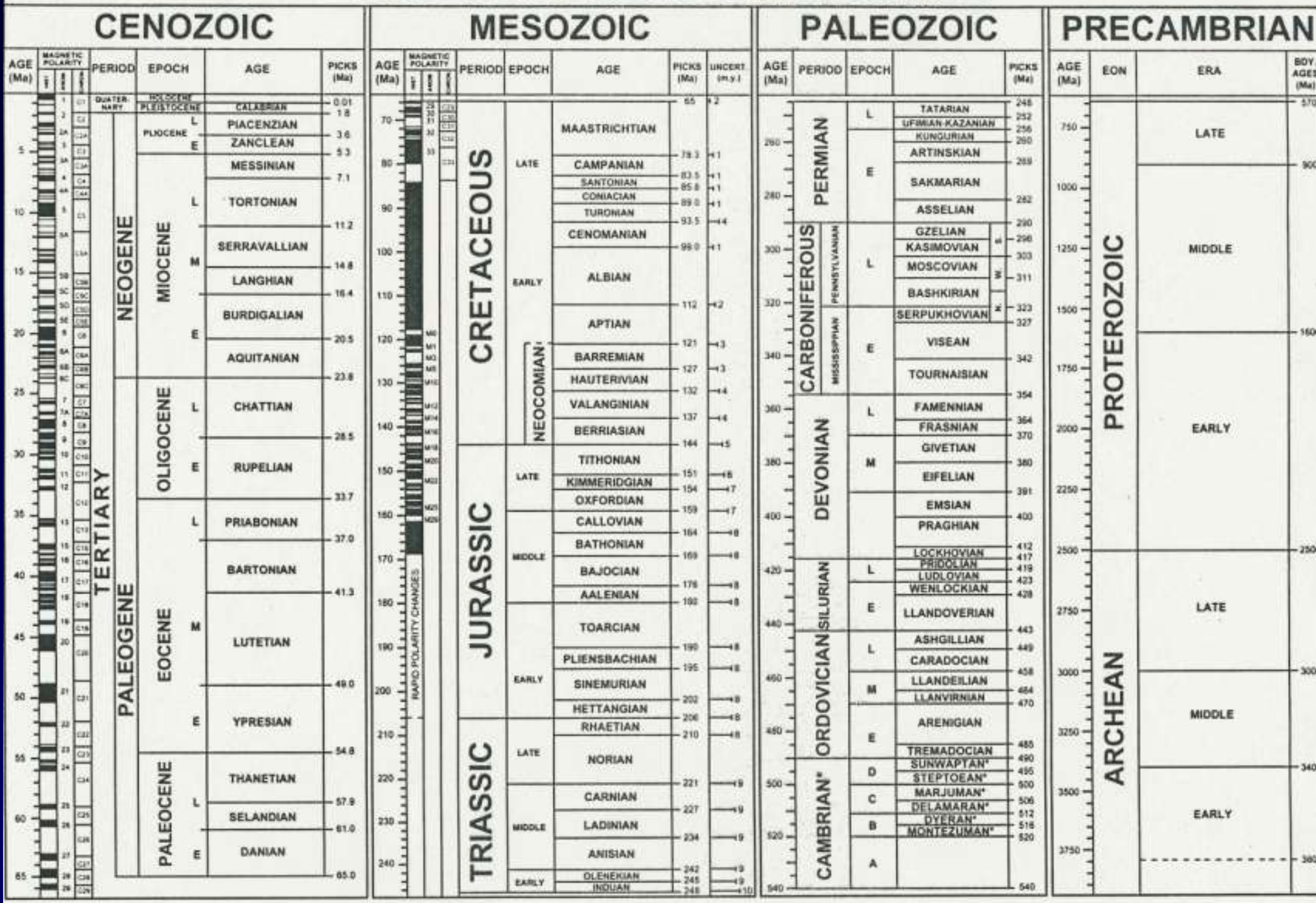
Paleozoic sedimentary rocks overlying Proterozoic Grand Canyon Group overlying Vishnu Schist

Geologic Time Scale



Nonconformity: Tintic Sandstone on Precambrian granite

1998 GEOLOGIC TIME SCALE



*International ages have not been established. These are regional (Laurentian) only.

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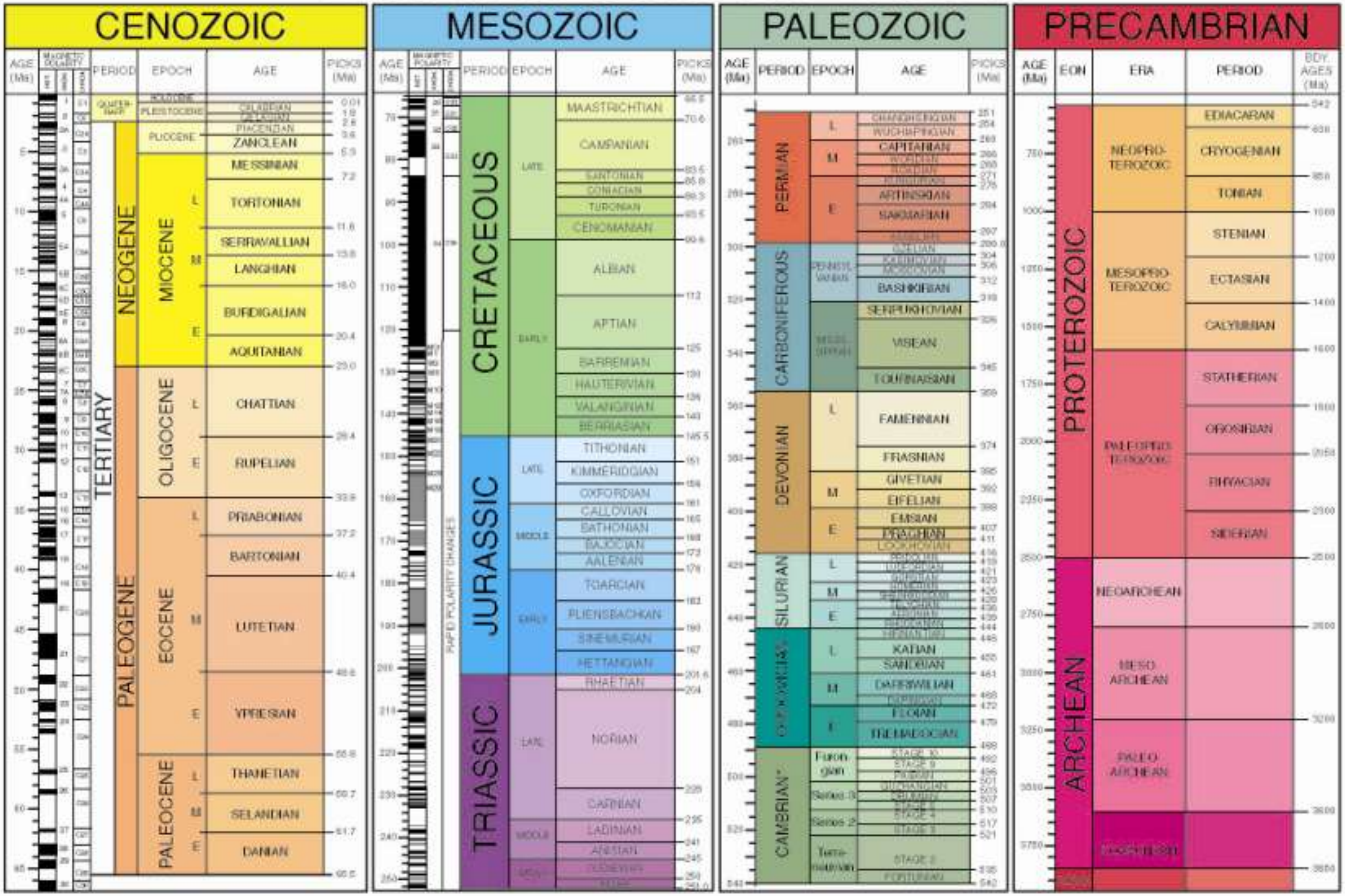
Sources for nomenclature and ages: Primarily from Gradstein, F. and Ogg, J., 1996, Episodes, v. 19, nos. 1 & 2, with Cambrian and basal Ordovician ages adapted from Landing, E., 1998, Canadian Journal of Earth Sciences, v. 35, p. 329-338, and Davidek, K., and others, 1998, Geological Magazine, v. 135, p. 305-309. Cambrian age names from Palmer, A.R., 1998, Canadian Journal of Earth Sciences, v. 35, p. 323-328.

2009 GEOLOGIC TIME SCALE



*International ages have not been fully established. These are current names as reported by the International Commission on Stratigraphy.

Walker, J.D., and Geissman, J.W., compilers, 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C. ©2009 The Geological Society of America.

Sources for nomenclature and ages are primarily from Gradstein, F., Ogg, J., Smith, A., et al., 2004, A Geologic Time Scale 2004: Cambridge University Press, 589 p. Modifications to the Triassic after: Furin, S., Preto, N., Rigo, M., Roghi, G., Gianolla, P., Crowley, J.L., and Bowring, S.A., 2006, High-precision U-Pb zircon age from the Triassic of Italy: Implications for the Triassic time scale and the Carnian origin of calcareous nannoplankton and dinosaurs: Geology, v. 34, p. 1009–1012, doi: 10.1130/G22967A.1; and Kent, D.V., and Olsen, P.E., 2008, Early Jurassic magnetostratigraphy and paleolatitudes from the Hartford continental rift basin (eastern North America): Testing for polarity bias and abrupt polar wander in association with the central Atlantic magmatic province: Journal of Geophysical Research, v. 113, B06105, doi: 10.1029/2007JB005407.

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TABLE 8.2 Major divisions of geologic time

TABLE 8.2 **Major Divisions of Geologic Time**

Cenozoic Era (Age of Recent Life)	Quarternary period	The several geologic eras were originally named Primary, Secondary, Tertiary, and Quaternary. The first two names are no longer used; Tertiary and Quaternary have been retained but used as period designations.
	Tertiary period	
Mesozoic Era (Age of Middle Life)	Cretaceous period	Derived from Latin word for chalk (creta) and first applied to extensive deposits that form white cliffs along the English Channel (see Figure 6.11).
	Jurassic period	Named for the Jura Mountains, located between France and Switzerland, where rocks of this age were first studied.
	Triassic period	Taken from word "trias" in recognition of the threefold character of these rocks in Europe.
Paleozoic Era (Age of Ancient Life)	Permian period	Named after the province of Perm, Russia, where these rocks were first studied.
	Pennsylvanian period	Named for the state of Pennsylvania where these rocks have produced much coal.
	Mississippian period*	Named for the Mississippi River valley where these rocks are well exposed.
	Devonian period	Named after Devonshire County, England, where these rocks were first studied.
	Silurian period	Named after Celtic tribes, the Silures and the Ordovices, that lived in Wales during the Roman Conquest.
	Ordovician period	
	Cambrian period	Taken from Roman name for Wales (Cambria), where rocks containing the earliest evidence of complex forms of life were first studied.
Precambrian		The time between the birth of the planet and the appearance of complex forms of life. More than 85 percent of Earth's estimated 4.6 billion years fal into this span.

SOURCE: U.S. Geological Survey.

*Outside of North America, the Mississippian and Pennsylvanian periods are combined into the Carboniferous period.

Grand Canyon

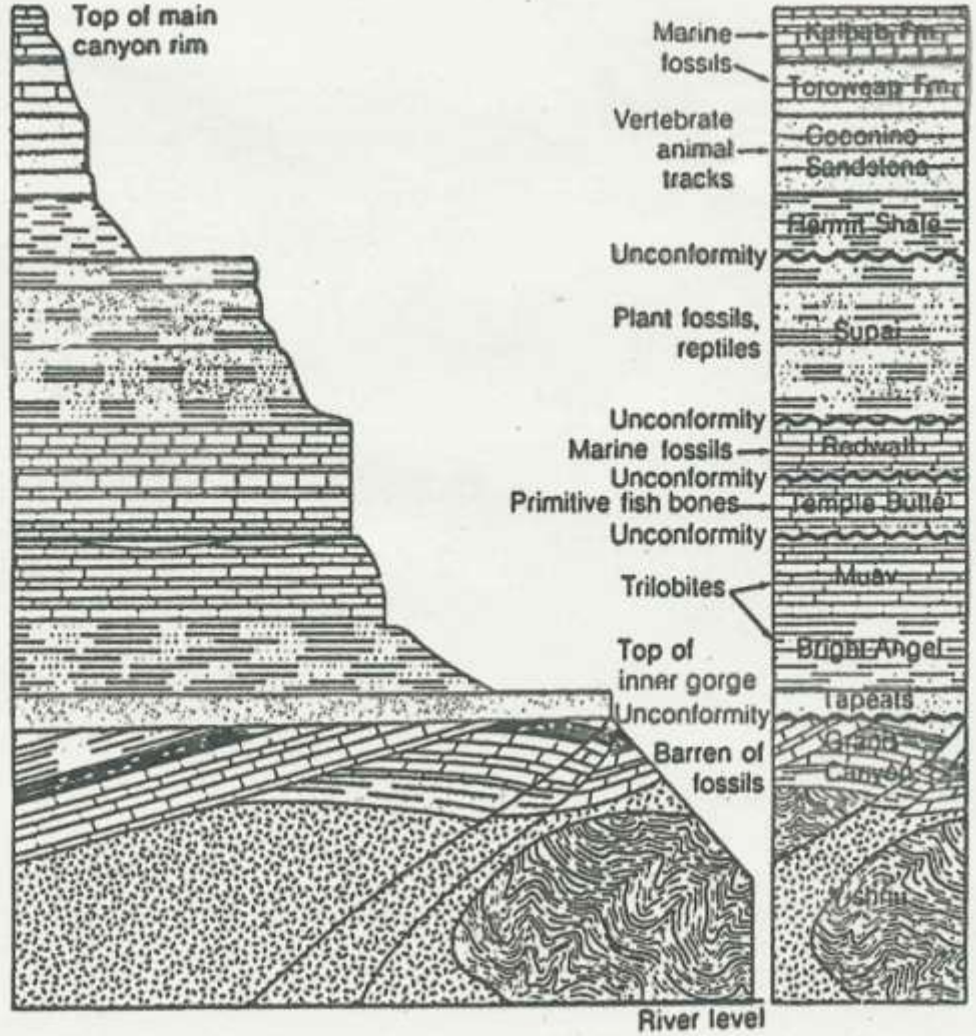


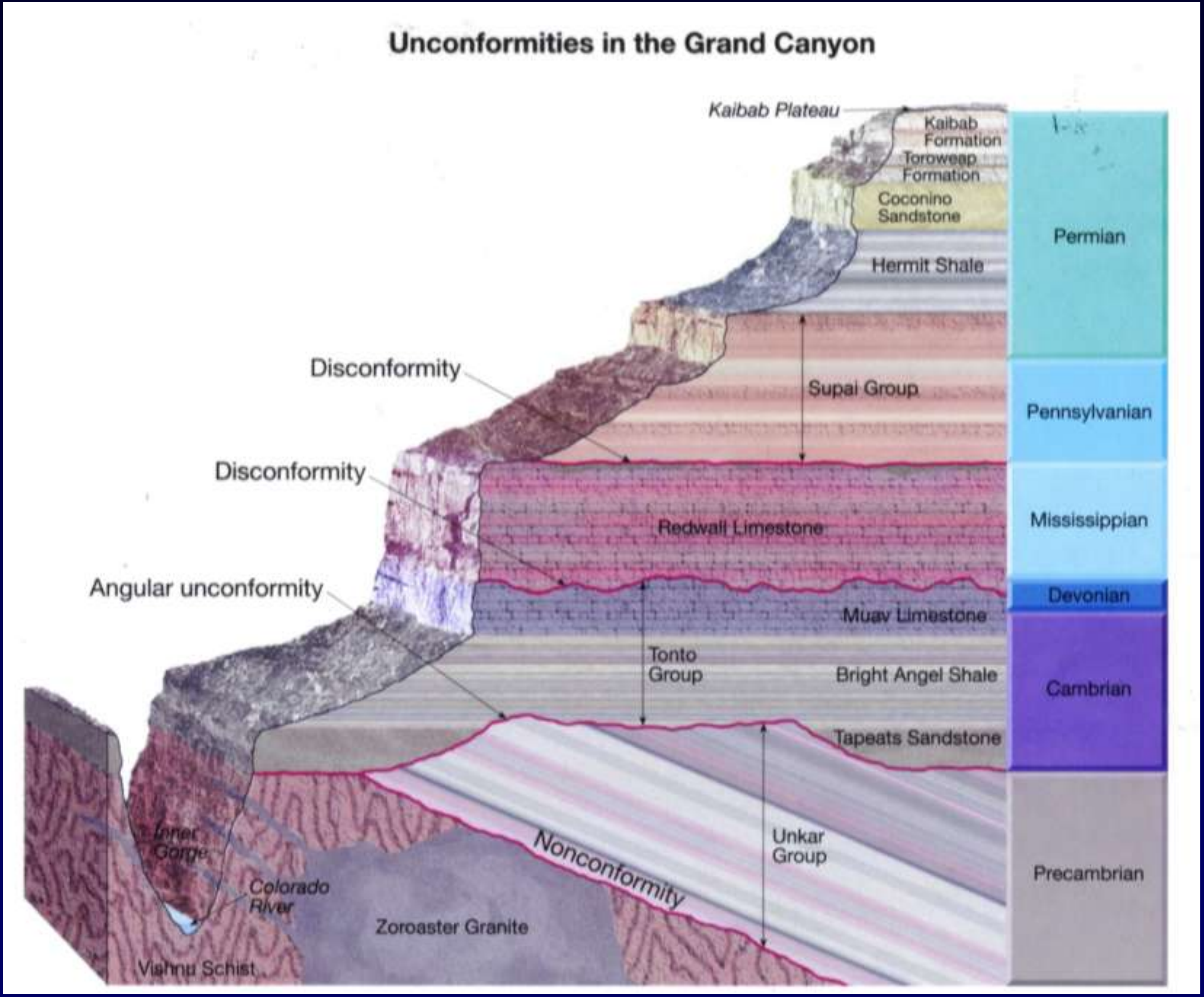
Figure 2-21
The Grand Canyon sequence. From the base up it consists of (1) the Vishnu (Precambrian), a complex group of metamorphic and igneous rocks; (2) the Grand Canyon series (Precambrian), tilted and faulted interlayered sandstones, shales, and limestones; (3) the Tapeats (Cambrian), a pebbly sandstone; (4) the Bright Angel Shale (Cambrian); (5) the Muav Limestone (Cambrian); (6) the Temple Butte Limestone (Devonian); (7) the Redwall Limestone (Mississippian); (8) the Supai Formation (Pennsylvanian), shales and sandstones; (9) the Hermit Shale (Permian); (10) the Coconino Sandstone (Permian); (11) the Toroweap Formation (Permian), mostly limestone; and (12) the Kaibab Limestone (Permian).

Tapeats Ss on Vishnu Schist

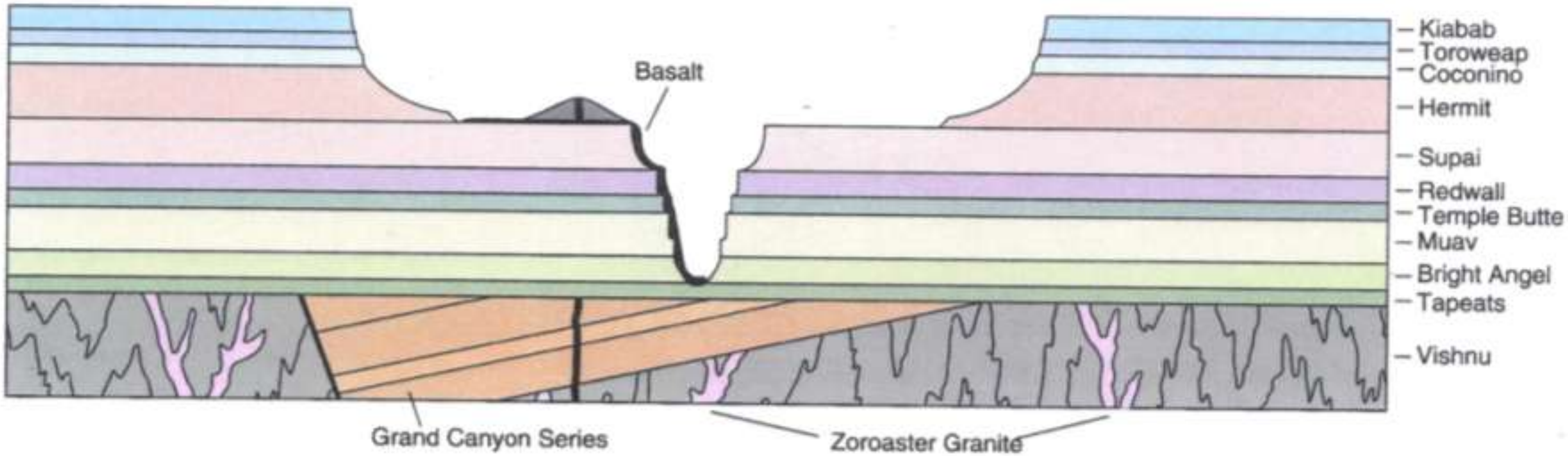
Formations in the Grand Canyon

A. View of the Grand Canyon from Lipan Point, approximately 30 mi east of the Visitor's Center. Two major rock bodies are exposed here. (1) The Grand Canyon Series consists of 12,000 ft of sandstones, siltstones, and limestones. Basalt (not exposed here) also occurs in this sequence as flows, dikes, and sills. The Grand Canyon Series is tilted 15 degrees to the east. (2) The Paleozoic sequence of rocks consists of nearly 5000 ft of sandstones, limestones, and shales that rest unconformably on the Grand Canyon Series. The rocks are essentially horizontal. Several unconformities occur in the sequence. The formations, from the base to the canyon rim, are: Tapeats Sandstone, Bright Angel Shale, Muav Limestone, Temple Butte Limestone, Redwall Limestone, Supai Sandstone, Hermit Shal Coconino Sandstone, and the Toroweap-Kaibab limestones.

Grand Canyon



General Formations in Grand Canyon



D. Composite Diagram Showing the Relationships of the Major Rock Bodies in the Grand Canyon

Grand Canyon sequence of events

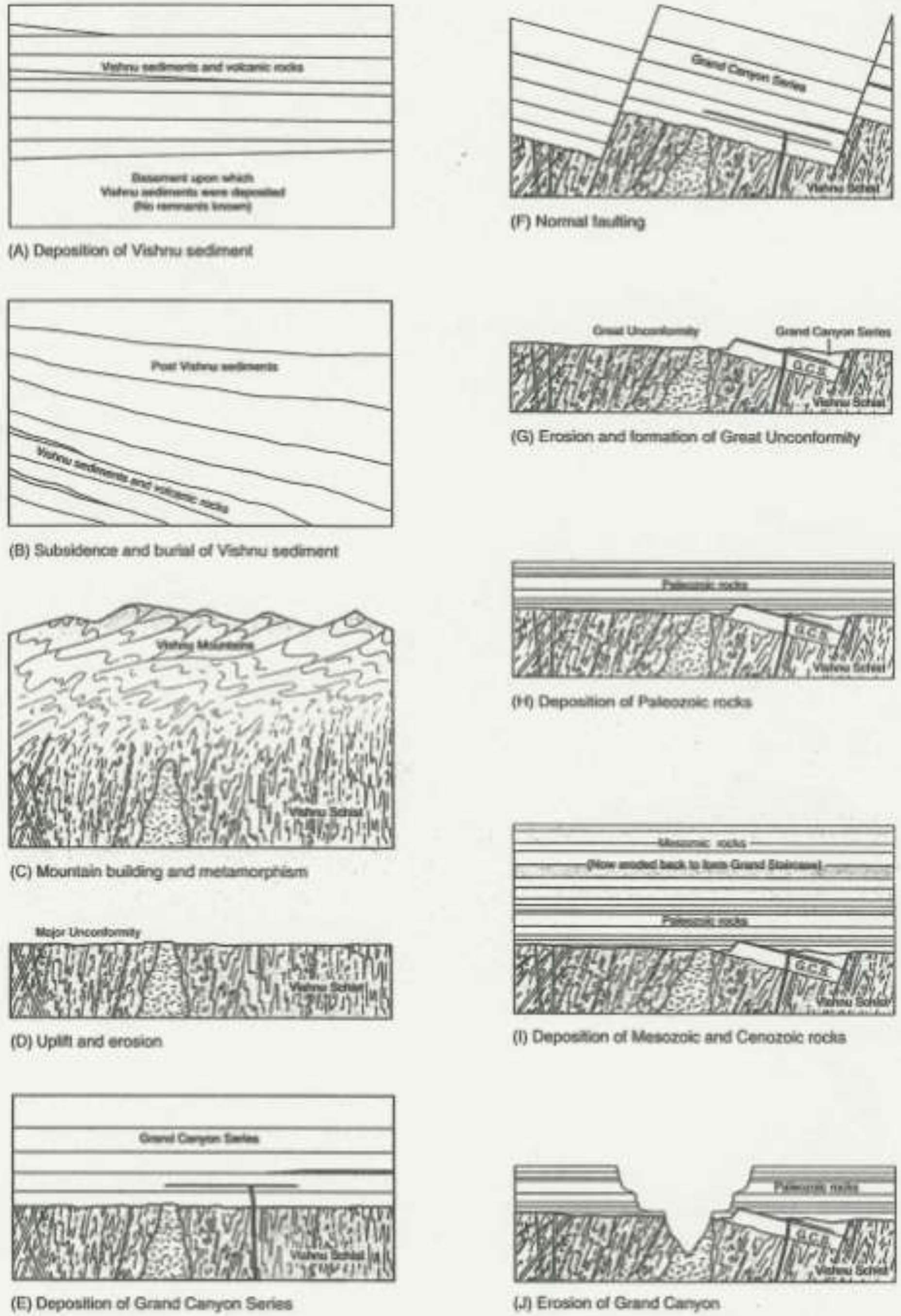


Figure 8.18 **The sequence of geologic events that formed the rocks and landscapes** of the Grand Canyon can be determined using the principles of superposition and crosscutting relations. The absolute ages of many of the events have been determined using radiometric dating.