Engineering Geoscience
ERTH2404

Maurice Lamontagne

Welcome!

- Earth is a <u>dynamic</u> planet!
- I would like this course to be dynamic as well by using:
  - Regular updates on geological events that have just occurred
  - Videos
  - Applications to your future career

During the next 12 weeks…

- We will probably witness:
  - About 3 magnitude 7 earthquakes worldwide
  - About 30 earthquakes in eastern Canada
  - A few landslides
  - A few volcanic eruptions
  - A few floods
  - A magnetic storm
  - Others (sinkhole, fireball?)

Maurice Lamontagne, P.Eng.

- B.A.Sc. in Geological Engineering
- M.Sc. and PhD in Geophysics and Earth Sciences
- Seismologist with NRCan since 1985
- Research Interests:
  - Intraplate earthquakes
  - Earthquakes induced by hydraulic fracturing and large hydroelectric reservoirs
  - Communications on earthquakes (before and after)

- Other: Hockey and hiking
  Amateur photography
  Volunteer at the Canada Aviation Museum

Questions?

- Raise your hand and ask!
- We can meet before or after the lectures…
- email: mauricelamontagne@cunet.carleton.ca
- I will update cuLearn with new material

Course Information

- Labs
  - Geoff Pignotta (Lab Coordinator): Geoff.Pignotta@carleton.ca
  - Starts this coming week

- Lab manual required: “Course pack”
  - Available at Science Stores, room 118 Steacie
  - Will be required for labs

Course Information

- Text Required: “Geology for Engineers and Environmental Scientists”, 3rd Ed., A.E. Kehew

  - Available at the bookstore
  - Secondhand books…

Course Evaluation

- A passing grade must be achieved in the lab and exams to complete the course.
- Multiple choice mid-terms and final

Material Covered			**% of final grade**
Lecture Exams	Midterm Exam	Lectures 1-5	30%
	Final Exam	Lectures 6-12	40%
Lab Work	Lab Exercises	Labs 1-4 (0.5% each)	2%
	Lab Exam	Covers Labs 1-4	10%
	Lab Exercises	Labs 5-10 (3% each)	18%
Total			100%

Course Dates

- January 16: Labs start (ODD)
- February 16: Midterm Exam (during class)
- February 23: Winter break
- February 13 - 16: Lab exam (during lab)
- Wednesday April 11: Last lecture

- See syllabus for details

Student Accommodation

- Disability, pregnancy, religious obligations
- May effect timing for exams, labs
- Alert me during first two weeks of class if need accommodation
- Deadline is Jan 20, 2017 for academic accommodations for the lab exam
- Equity Services website:
  http://carleton.ca/equity/accommodation

Other Information

- CuLearn
  - All course information posted online
  - Sign on through Carleton website main page
- Deferred exams
- Plagiarism

As a Courtesy…

- Carleton University has a commitment to provide an appropriate environment for learning.
  - Respect
  - Keep noise level low
  - Avoid distracting others

Breaks

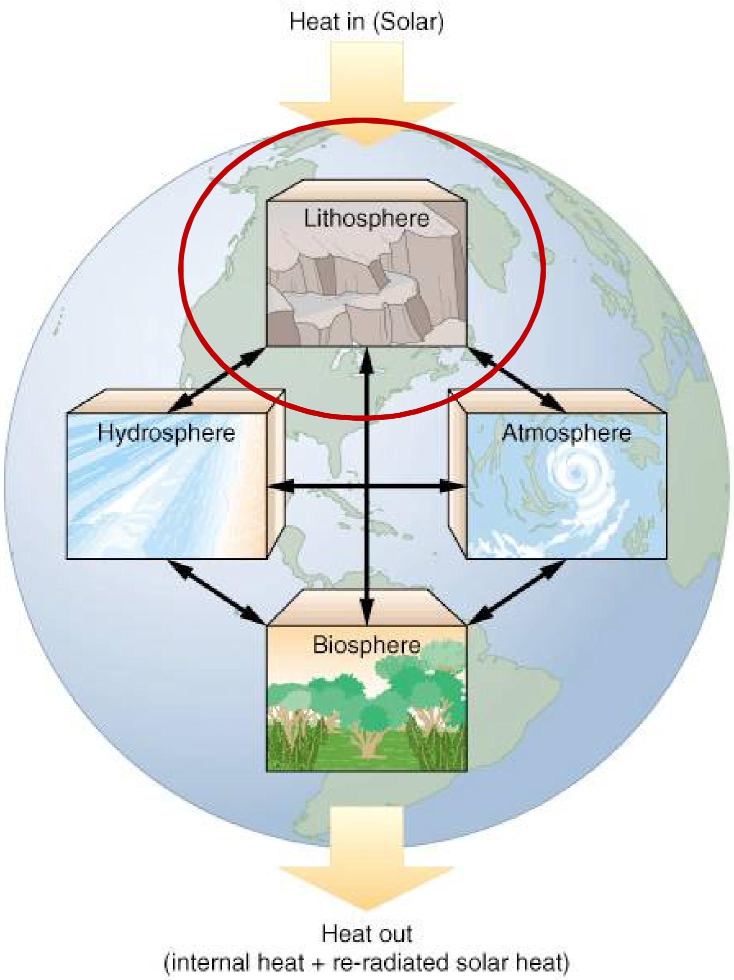
- Every 50 minutes; a 5-10 minute break
- I suggest that we get up and stretch
- Relax; walk around
- Check your messages, etc

We all agree?

- Questions?

Subject of this course:
the ”solid” part of our planet!

What this course has to offer



- Study of our planet:
  The solid part (lithosphere)
  and its interactions with atmosphere, hydrosphere, space

- Implications of earth science problems to engineering

Why Earth Sciences?

- Video by the America Geological Institute
- https://www.youtube.com/watch?v=j1cKBuxBWKY

Earth Sciences Specialties

The Four Earth Sciences:

- Geology: “Solid Earth, Lithosphere”

- Meteorology: “Atmosphere”
- Oceanography : “Hydrosphere”
- Astronomy : “Space”

Some Geoscience Fields

Geology

- Structural geology / Tectonics
- Geomorphology
- Glaciology
- Hydrogeology
- Mineralogy / Petrology / Crystallography / Geochemistry
- Paleontology / Paleoclimatology
- Sedimentology / Stratigraphy
- Volcanology
- Exploration geology

Geophysics

- Seismology
- Gravity
- Geomagnetism
- Exploration geophysics

Others

- Geodesy
- Remote sensing

Course Topics

- Geological Time
- Minerals and Rocks
- Plate tectonics, volcanoes, earthquakes
- Rock mechanics and structures
- Glaciers
- Mass movement (landslides)
- Hydrology
- Earth resources

Course Objectives

- At the end of term, you will be:
  - Able to describe earth materials and processes from both engineering and geological perspectives
  - Aware of the potential impact of geological processes on engineering work
  - Familiar with the specialized vocabulary of earth sciences
  - Able to travel differently

Today’s Lecture

- Relative dating
- Absolute dating
- Geological time scale

Today's lecture topics

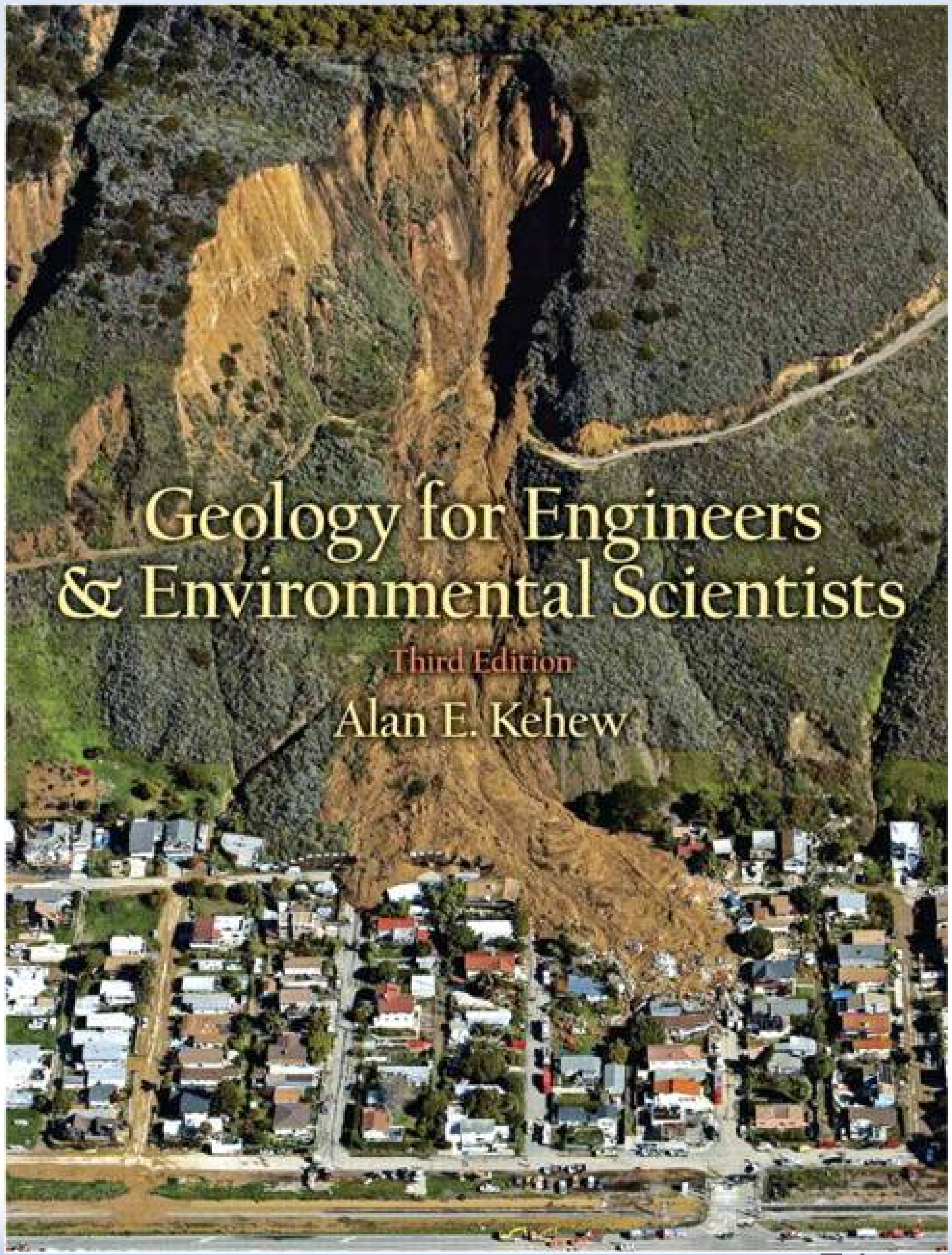
- The origin of the Solar System
- Time scale applied to geological processes; relative and absolute
  - Principles behind radiometric dating
  - To place rock units and geological events in chronological order using Steno's Rules
- Geological history: global and Canada's

Reading

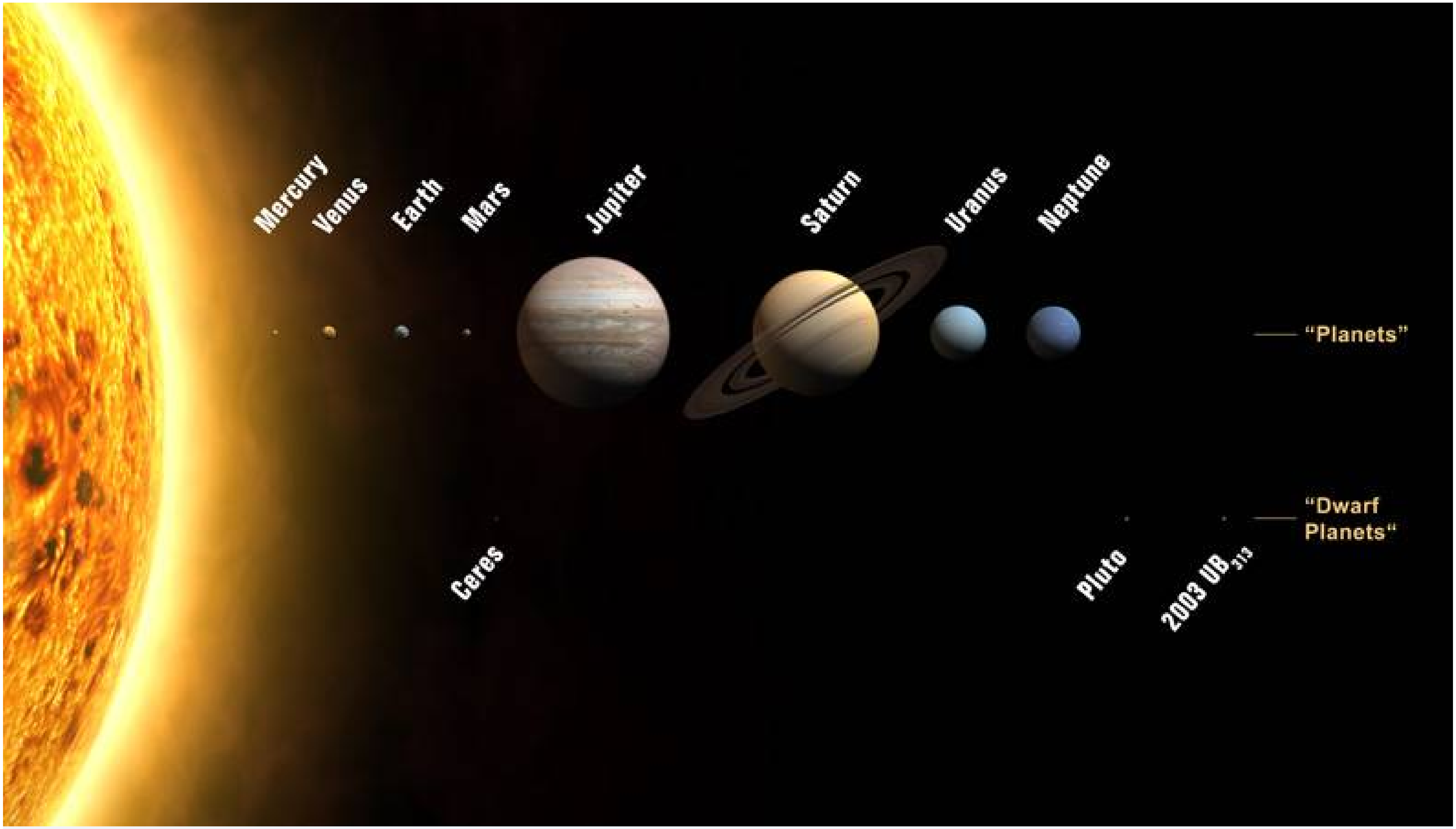
- Please read Kehew's book to complement the material presented in this lecture:

Chapter 2,

p. 23-27; p. 60-72;



Our solar system



Credit: International Astronomical Union

The origin of the Solar System

- Model must account for the following observations:
  - All planets rotate in same direction around the Sun
  - The orbits of all planets lie in the same plane, the **invariable plane** (Earth's orbital plane is the **ecliptic plane**)
  - The distribution of planetary bodies:
    - Terrestrial planets, asteroid belt, giant planets, comets
  - Planets have different:
    - Rotation periods, spin directions, obliquity

The origin of the Solar System

“Classical” Model

1. Formation of Solar Nebula
2. Planetesimals
3. Planetary accretion
4. Planetary differentiation

Video: The origin of the Solar System

https://www.youtube.com/watch?v=x1QTc5YeO6w

1. Solar Nebular

- The sun and planets are born from a rotating disk of cosmic gas and dust, the **solar nebula (**Kant,1755)

- Cloud spins faster and flattens to form a disk, constraining the planets

  - Explains why all planets orbit the Sun in the same direction
  - Explains why all planets have their orbits in the same plane

1. Solar Nebular

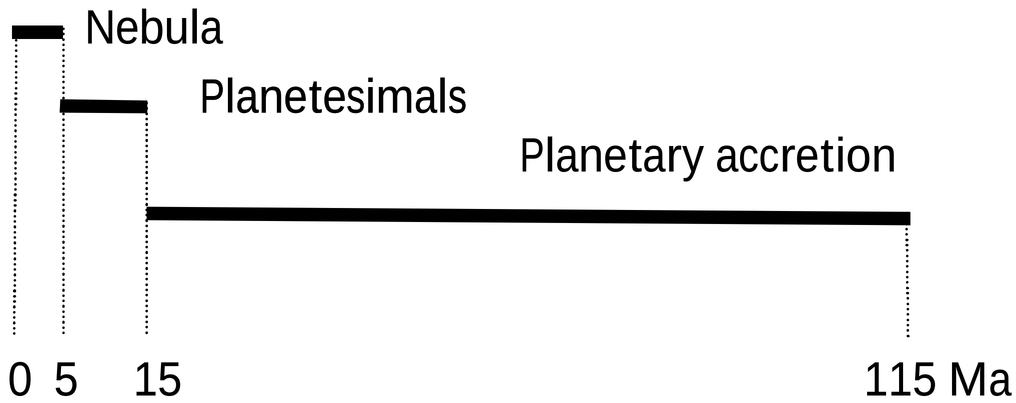
- The solar nebular is influenced by gravity, gas pressure, and rotation
- Mass collapses at centre forming the Sun
- Cloud spins faster and flattens to form a disk, constraining the planets:
  - Explains why all planets orbit the Sun in the same direction
  - Explains why all planets have their orbits in the same plane

2. Planetesimals

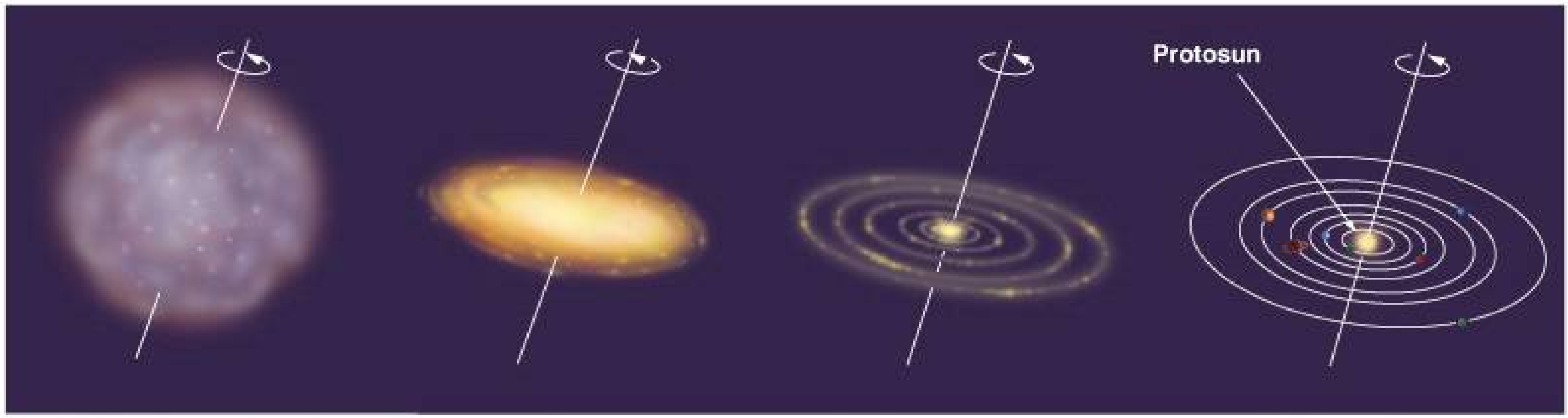
- Mass flow between sun and disk ceases
- Accretion of **planetesimals**
  (diameter ≤ 1 km)
  - Sources of energy:
    - Gravitational energy
    - Impact energy
- Controlling factor: falloff in T with distance from the sun

3. Planetary accretion

- Planets resulting from accretion from a small number of large planetesimals in the final stage
  - Disruption of spin and obliquity
- All planets formed:
  - At the same time (≈ 4.6 Ga), in a relatively short time



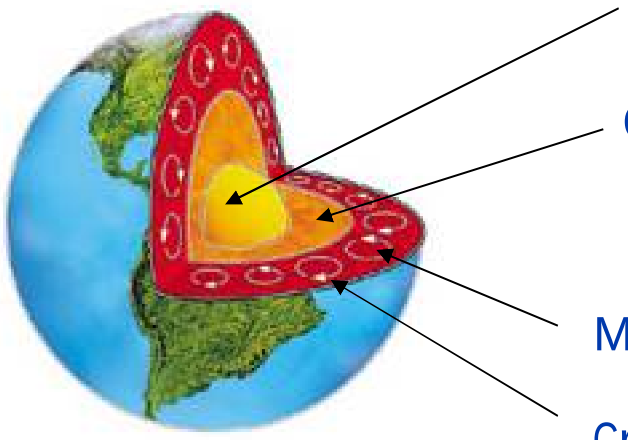
The origin of the Solar System



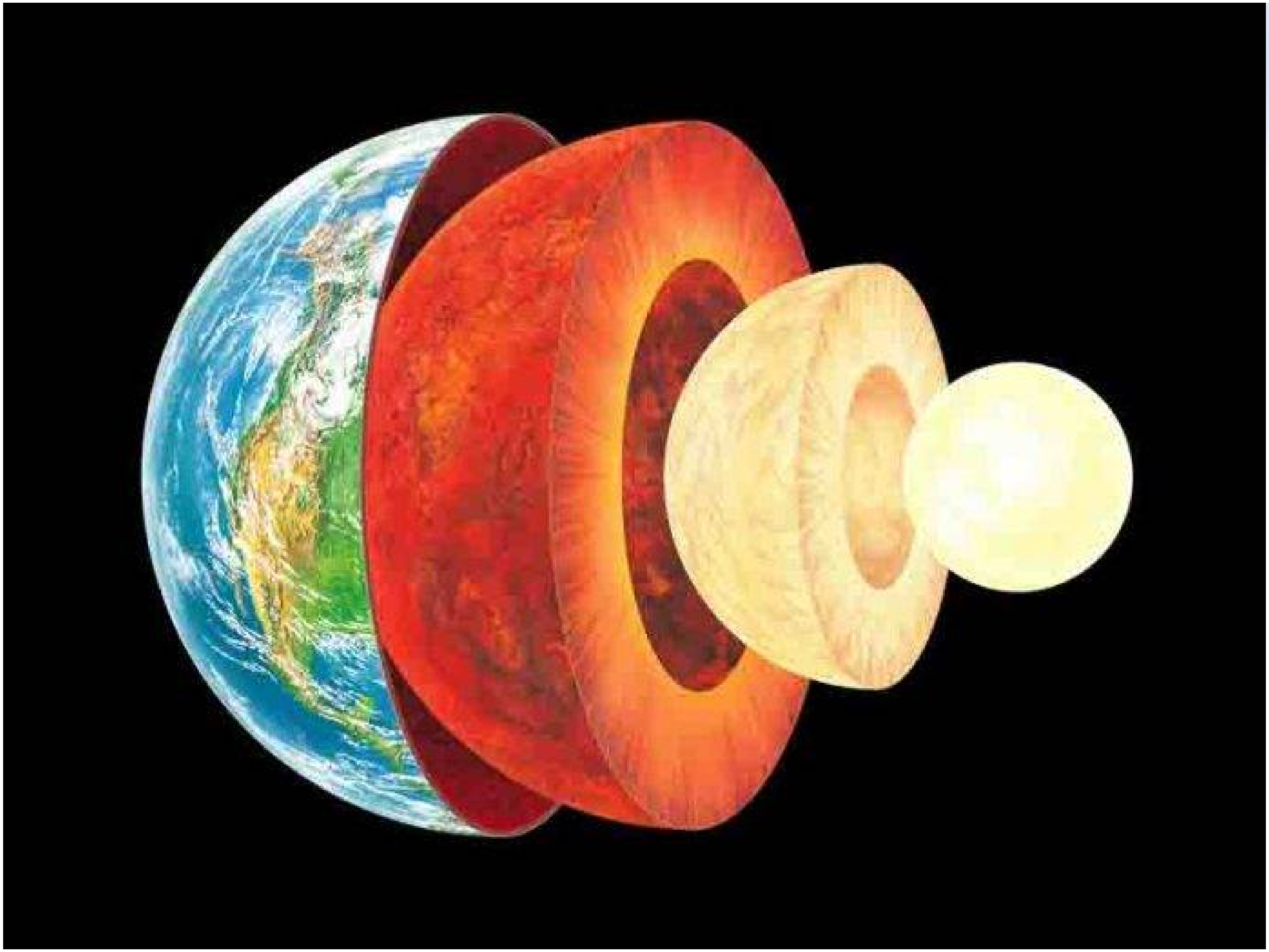
1. Cloud rotates more rapidly as it contracts
2. Cloud flattens to pancake-like form
3. Rings form
4. Planets form at their present distances from Sun

Davidson et al., 2002

4. Earth Differentiation



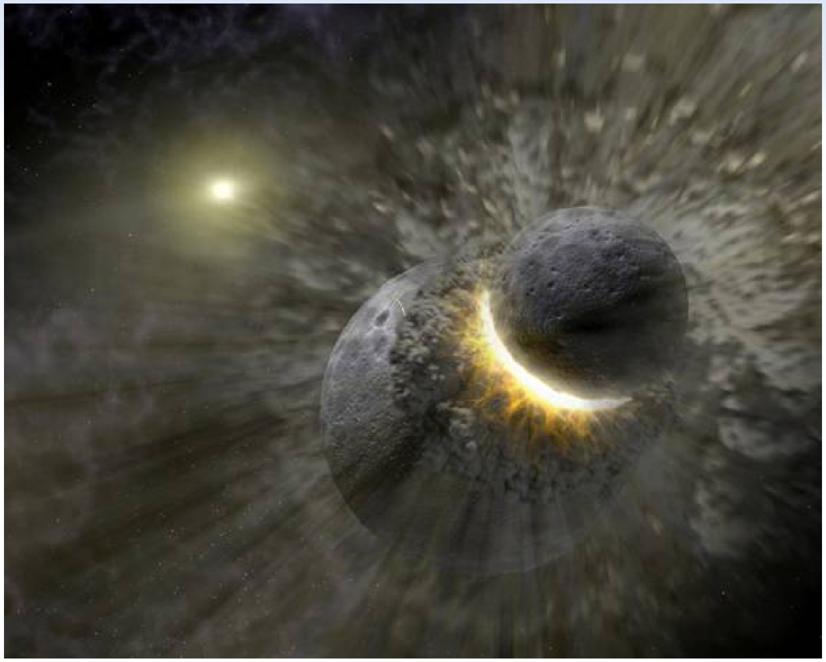
- Denser material migrates gradually to the centre
- Initial Earth hot, mostly molten; separates into dense Fe-Ni alloy core and silicate mantle by gravity



Inner Earth. Credit: Gary Hincks/Science Photo Library

Earth’s Moon

- Moon less dense than Earth, cannot have formed at same time by same processes
- Collision model for Moon;
- Less dense silicate material ejected into orbit together with material from impactor a Mars-sized impactor named Theia formed Moon at 4.53 Ga



Credit: NASA

Meteorites

- Most tell us the age of the Solar Nebula
- Most come from asteroids of the asteroid belt (a few from Mars and the Moon)
- “Stony meteorites” are primitive
    - Composition similar to Earth’s mantle
    - Chondrules are solidified droplets of matter from the early Solar Nebula
- “Iron meteorites” are differentiated
    - Composition similar to Earth’s core
- Stony-Irons
    - ⍰ Mixture of the above

Meteorites

Stony meteorite, Murchison, with abundant chondrules

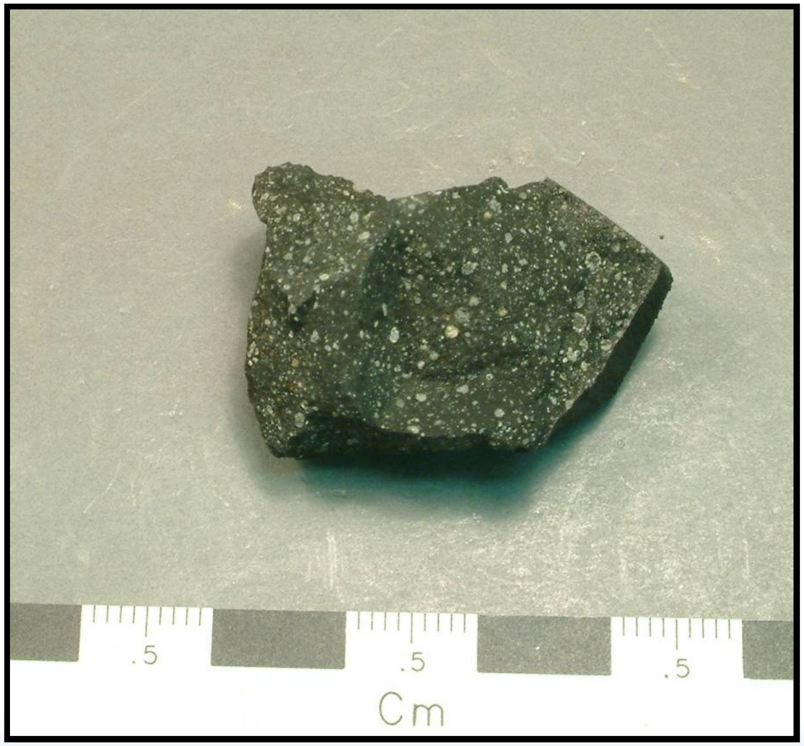
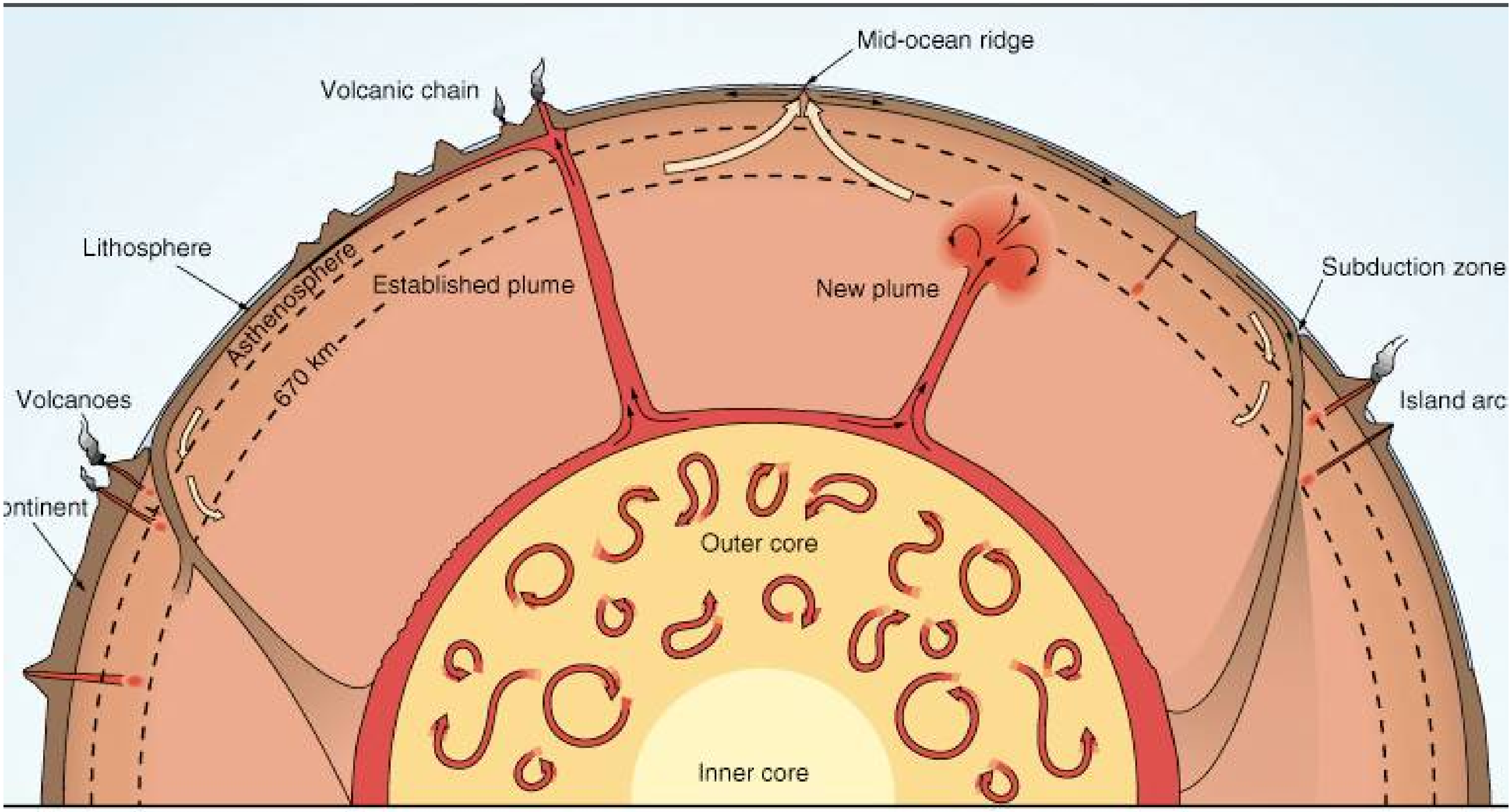


Photo: D. Smith, Carleton U.

Iron meteorite, Annaheim, found in 1916, 100 km east of Saskatoon by a farmer mowing hay

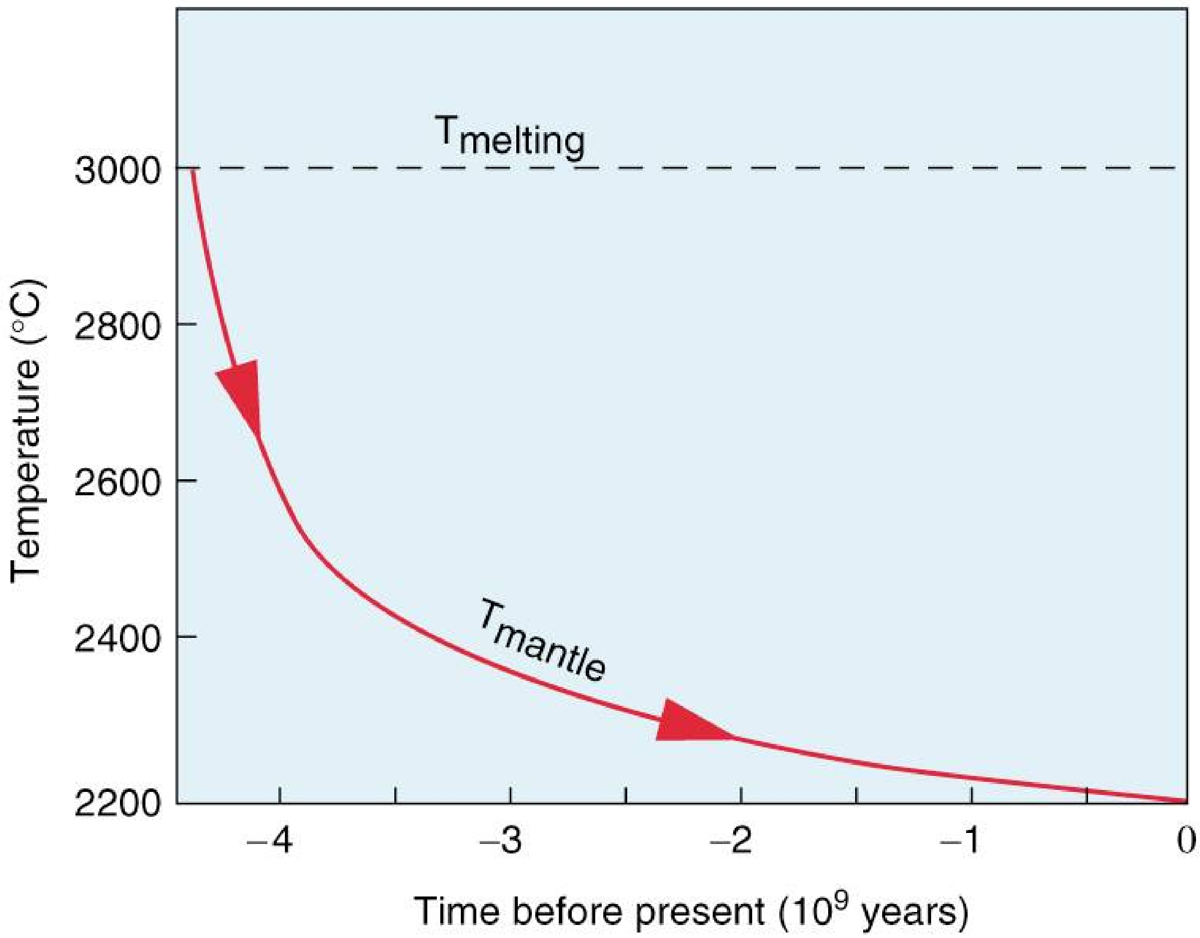
Photo: http://miac.uqac.ca/MIAC/

The Modern Earth



The Earth's core is cooling

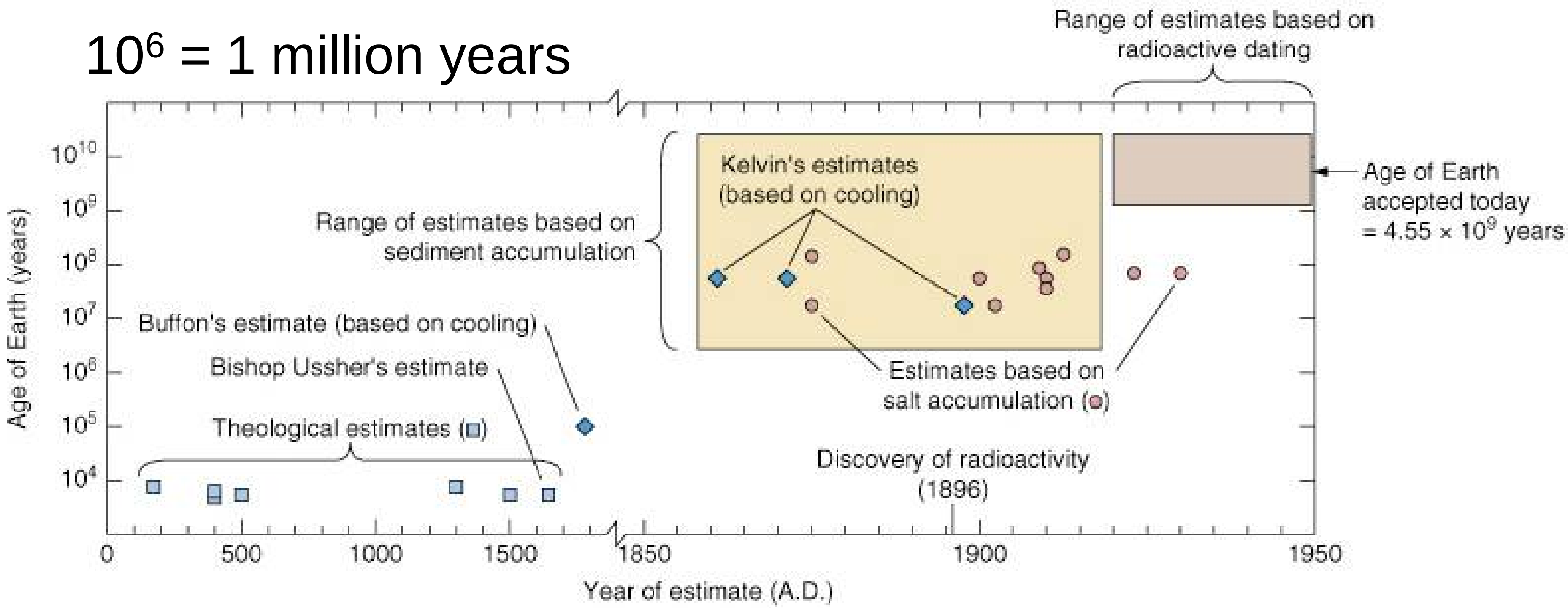
Earth inherited *Primordial Heat*; also produces heat from *radioactive decay* of K, U, Th



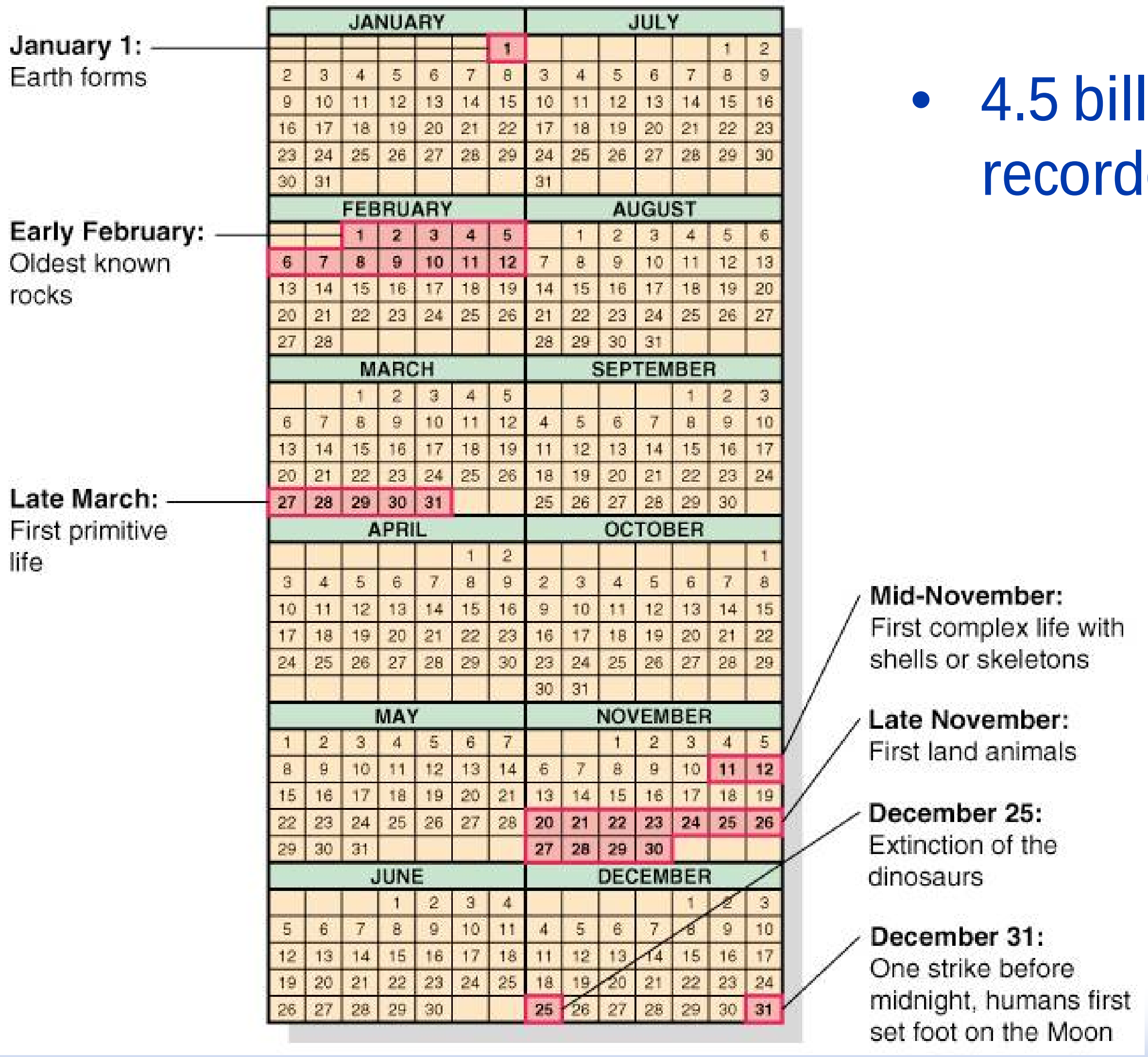
Earth History: the Age of the Earth

- Theological, sediment accumulation, Earth cooling rates, radioactive decay

10^6 = 1 million years



Lecture 1: Geologic Time



- 4.5 billion years of history recorded in rocks

Earth History: the Age of the Earth

- James Hutton (1726 – 1797)
  - Founder of modern geology
  - Major contribution:
    - Earth's core is hot
    - Based on erosion rates, the Earth is several orders of magnitude older than previously thought

  - Key field evidence: unconformity at Siccar Point

Earth History: the Age of the Earth

Siccar Point, Scotland

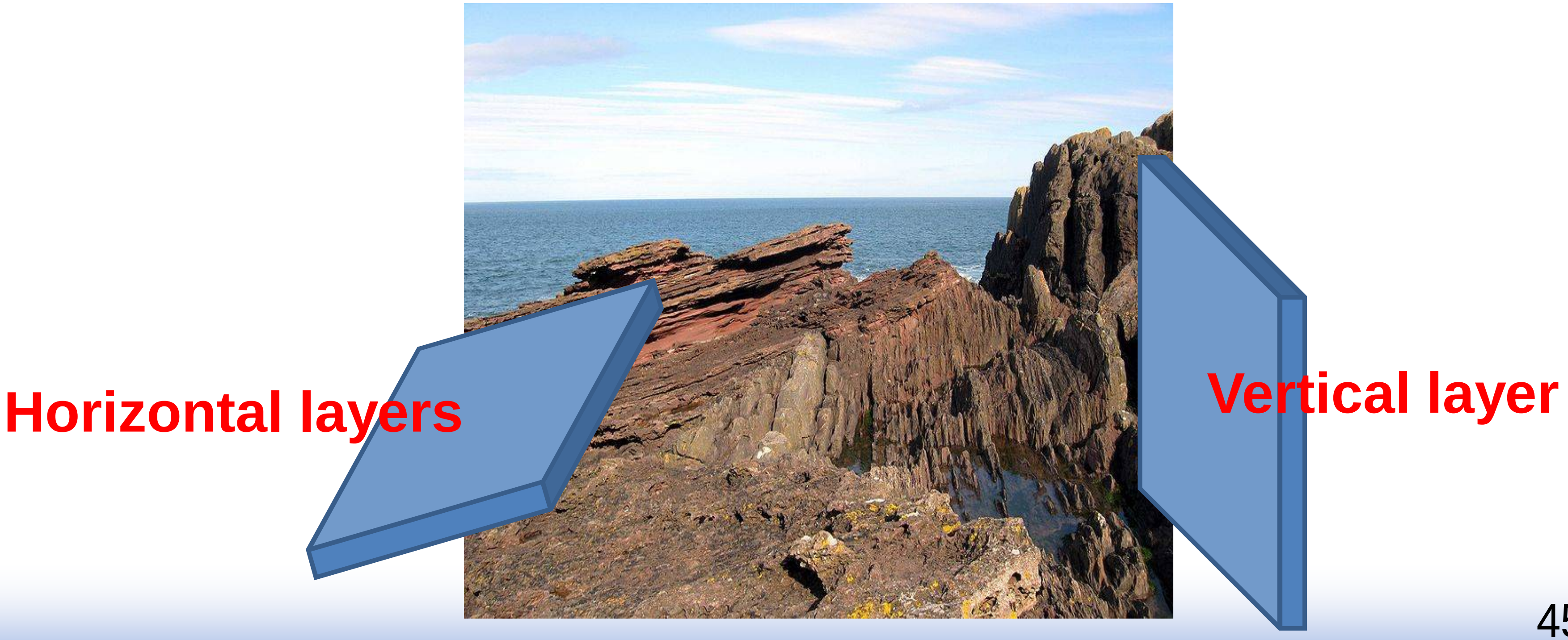
Earth History: the Age of the Earth

- How the earth was made (History Channel)
- https://www.youtube.com/watch?v=HoRIXgNK-J8

- Siccar Point, Scotland

James Hutton

- Key observation at Siccar Point, Scotland
  - Presence of horizontal and vertical layers
  - What is the significance of this observation?
  - There are forces/events happening to cause the orientation of the layers to become vertical



Relative dating

- **Relative dating**: task of placing rock units and geological events in chronological order
  - in their proper sequence

- We use four laws to guide relative dating in geology

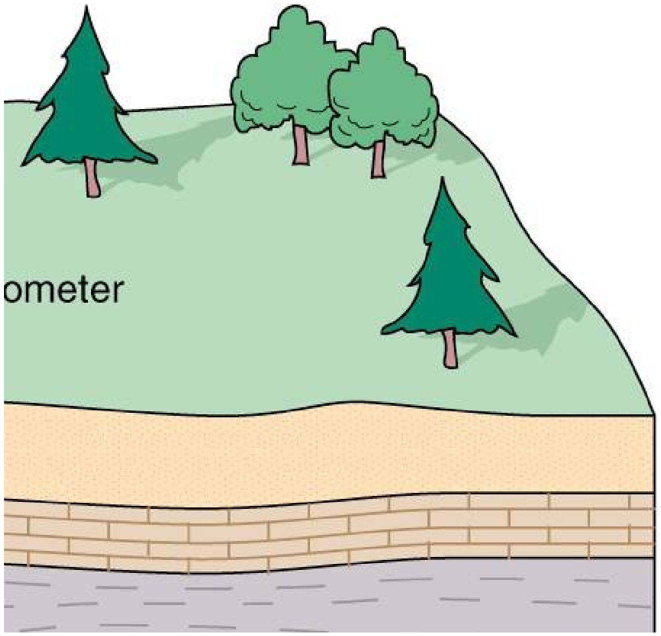
Steno's Rules

- Nicholas Steno, 1638-1686

  1. Principle of original horizontality
  2. Principle of lateral continuity
  3. Principle of superposition
  4. Principle of cross-cutting relationships

- Steno's Rules 1-2-3 apply to **sedimentary rocks**

1. Principle of Original horizontality



- Layers of **<u>sediments</u>** are always deposited in horizontal sheets
  - Acceptable assumption for scale

    < 100 kms

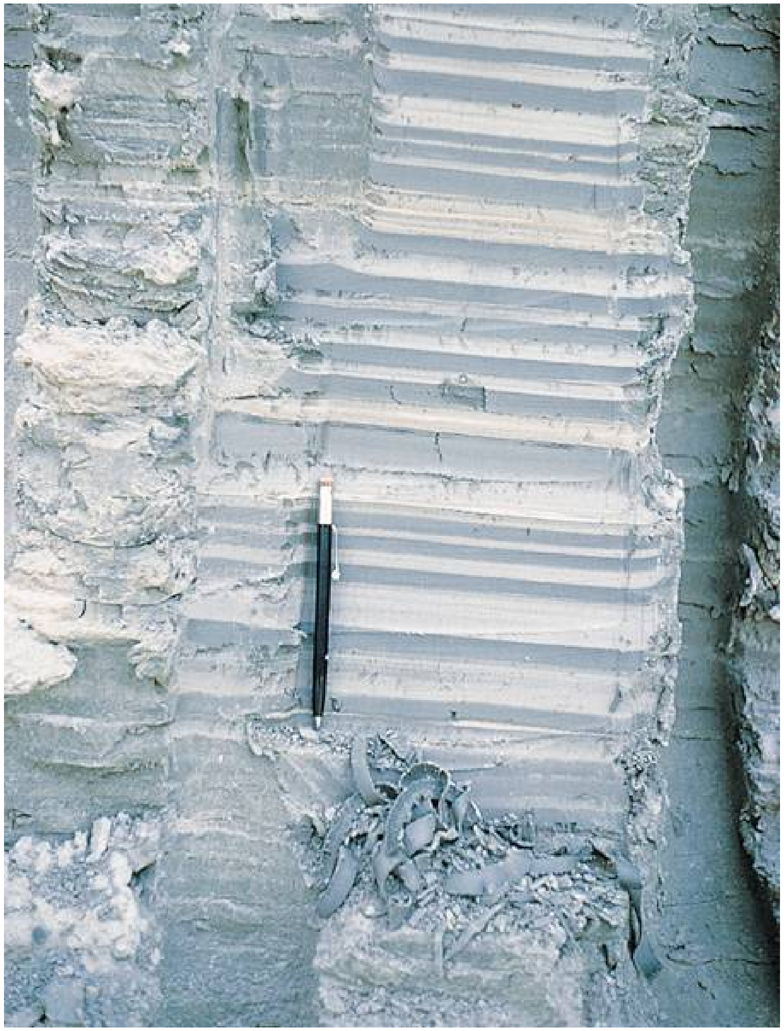
  - When layers are deposited one after the other without interruption, they are **conformable** (continuous, unbroken strata)

  - **If not, they have been disturbed**

2. Principle of Lateral continuity

- **Sediments** are deposited in continuous horizontal sheets up to the point where they terminate against a solid surface

3. Principle of Superposition



- In undeformed sedimentary rocks, each layer is older than the one above it

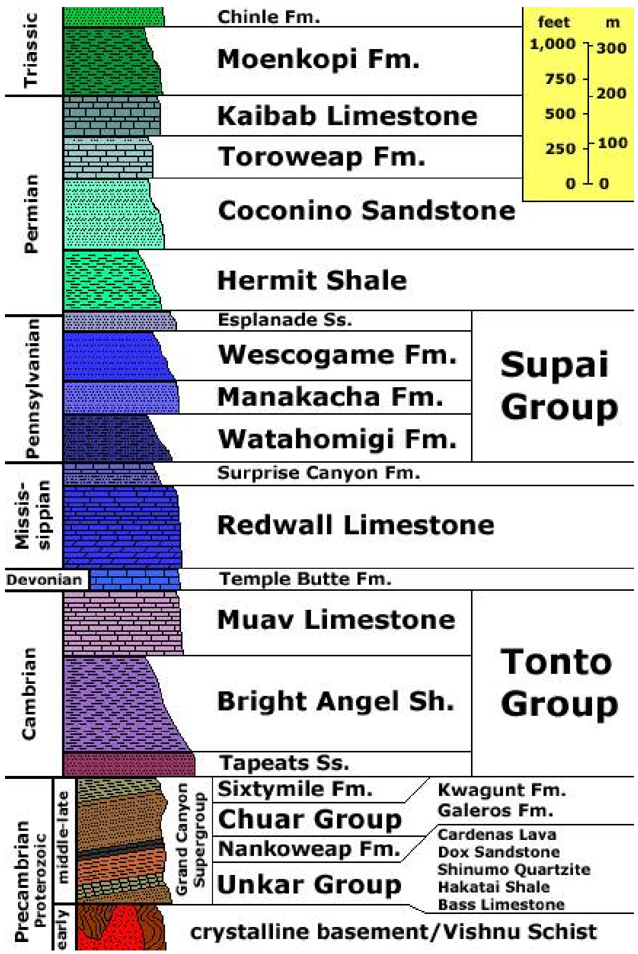
(or each one above is younger than the one below)

- If layers are folded or inclined at a large angle, they have been disturbed **after deposition**

Grand Canyon, Arizona

Younger

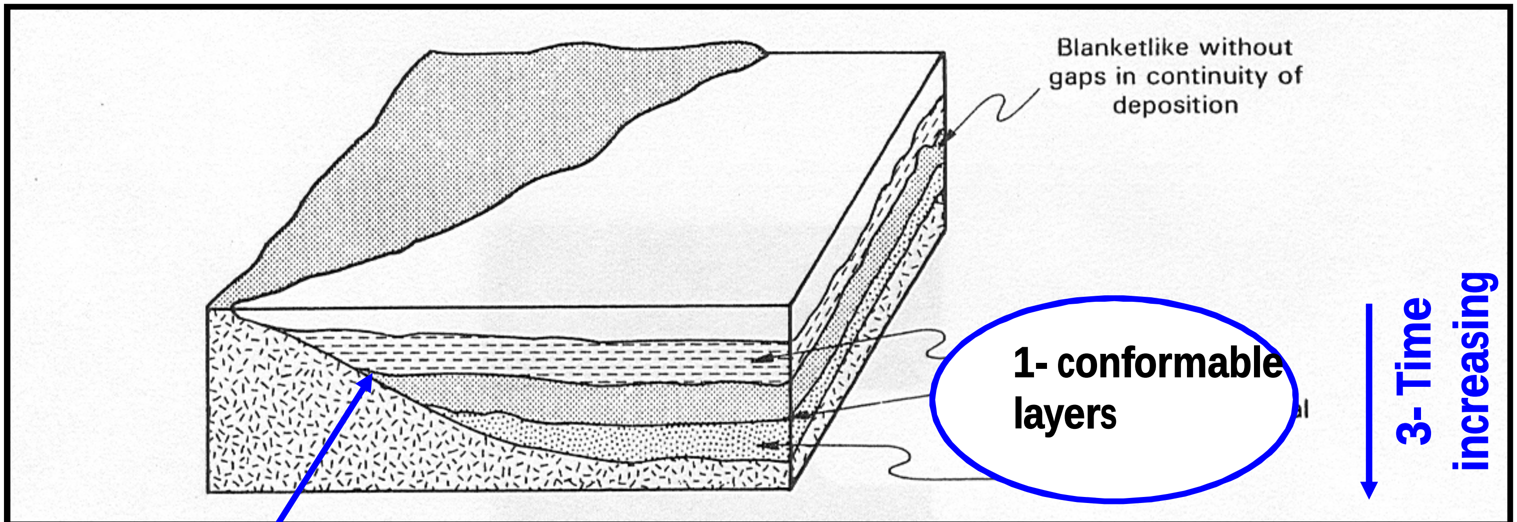
Time increasing



Older

Source: National Park Service

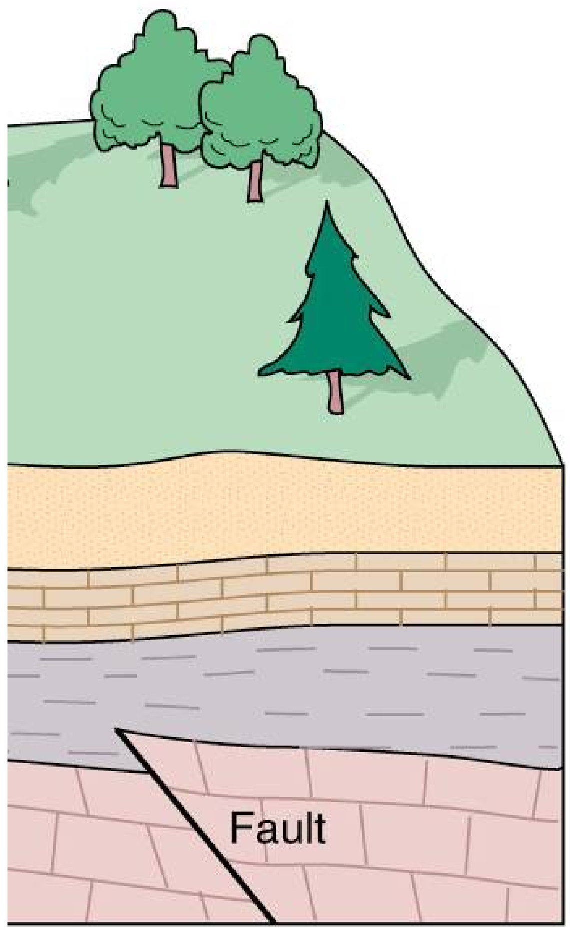
Rules 1, 2, and 3



Ref.: Kehew, A.E. 1995. Geology for Engineers & Environmental Scientists. 2nd Edition. Fig. 1.1. Shown with permission.

2- Older surface predating sediment deposition

4. Principle of Cross-cutting relationships



Any “event” that cuts or breaks a rock must be younger than that rock

- Fault
- Intrusive

Unconformities

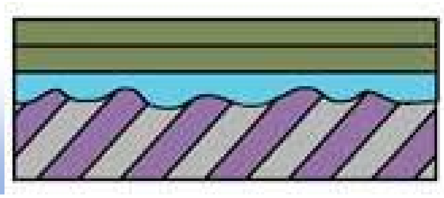
- In most places on Earth, there is no complete set of conformable layers.
  - Surfaces left by halts in sedimentation are called **unconformities**

A- Angular unconformity: older layer dip at an angle different from younger layer

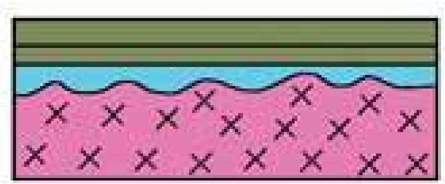
B- Nonconformity: the erosion surface is an igneous or metamorphic rock

C- Disconformity: is an erosional surface separating horizontal strata below from horizontal strata above and where there is a gap in time.

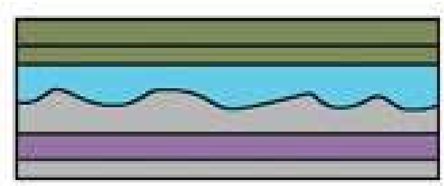
A



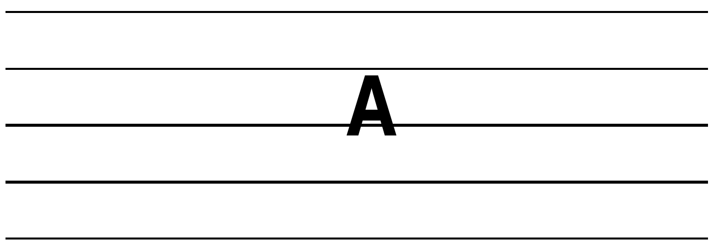
B



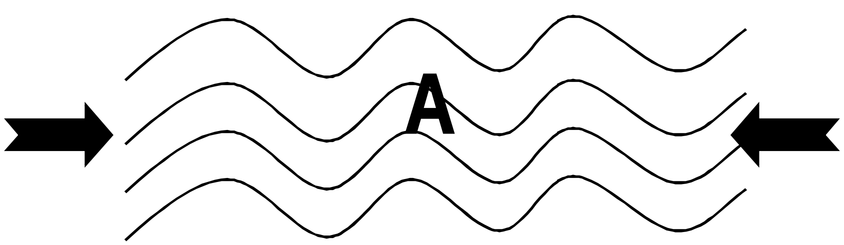
C



Unconformities

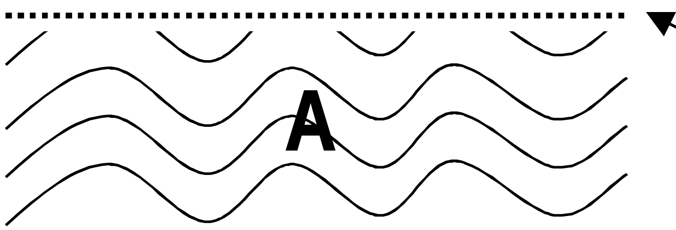


- Deposition of Sequence A in **conformable layers**



- Deformation & metamorphism of sequence A

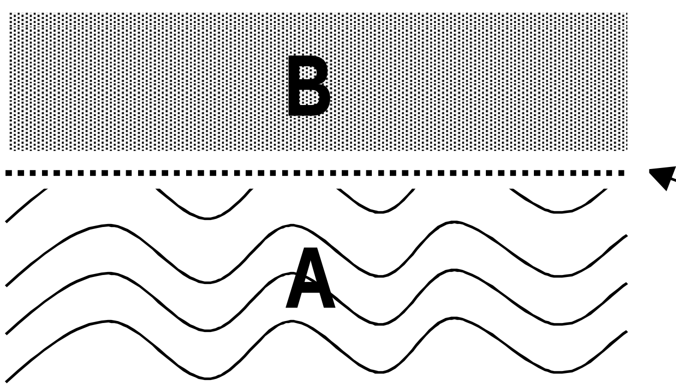
Unconformities



Example 2

- Erosion of A

Erosional surface

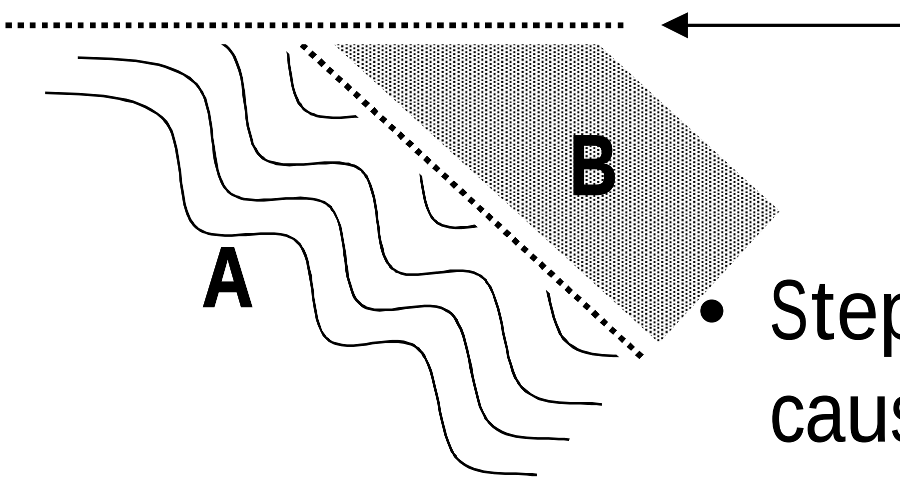


Example 3

- Deposition of sequence B

Nonconformity

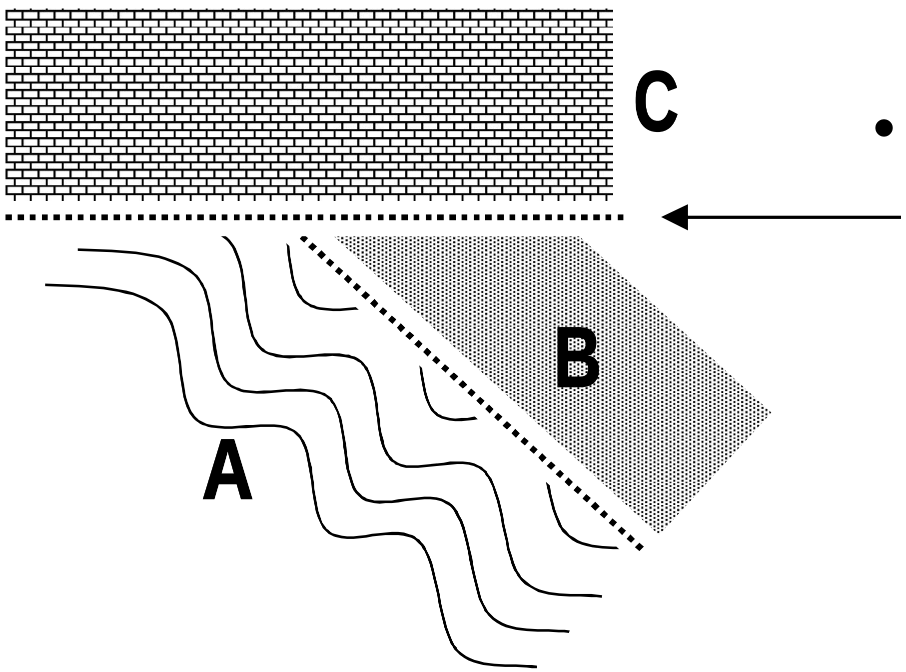
Unconformities



- Step 2: Erosional event leads to **Erosional surface**

- Step 1: Forces cause Sequence AB to uplift

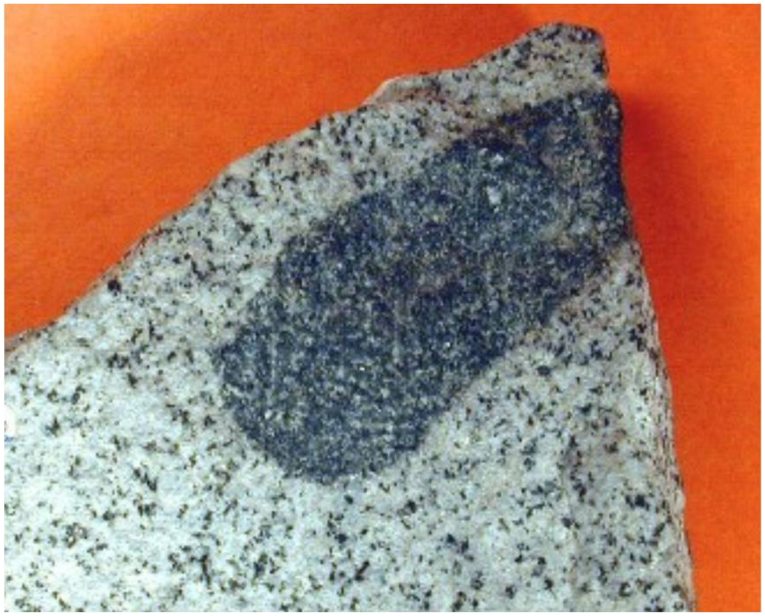
Unconformities



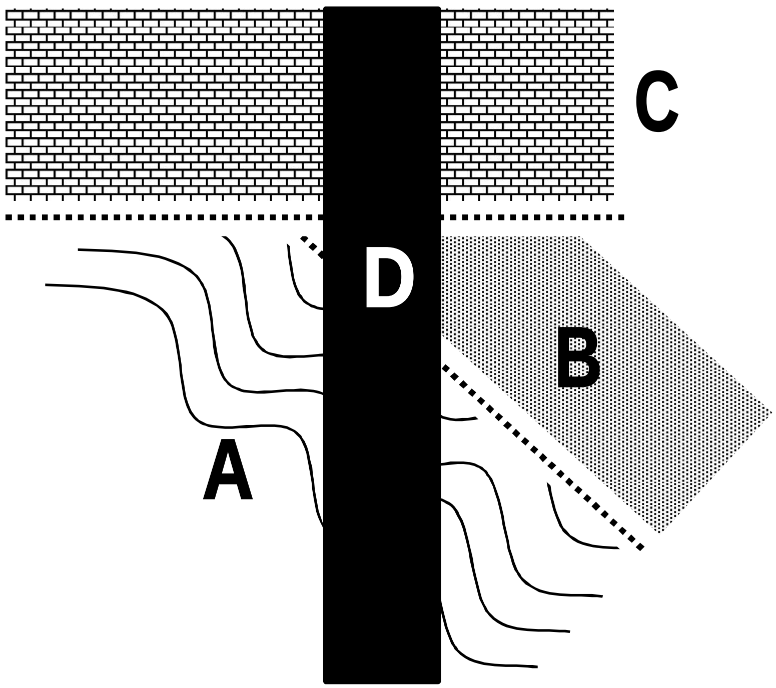
- Deposition of sequence C leads to **Angular unconformity**
- Layers are no longer conformable

Law of included fragments

- If fragments of one material are found in another, then the included fragments must be older



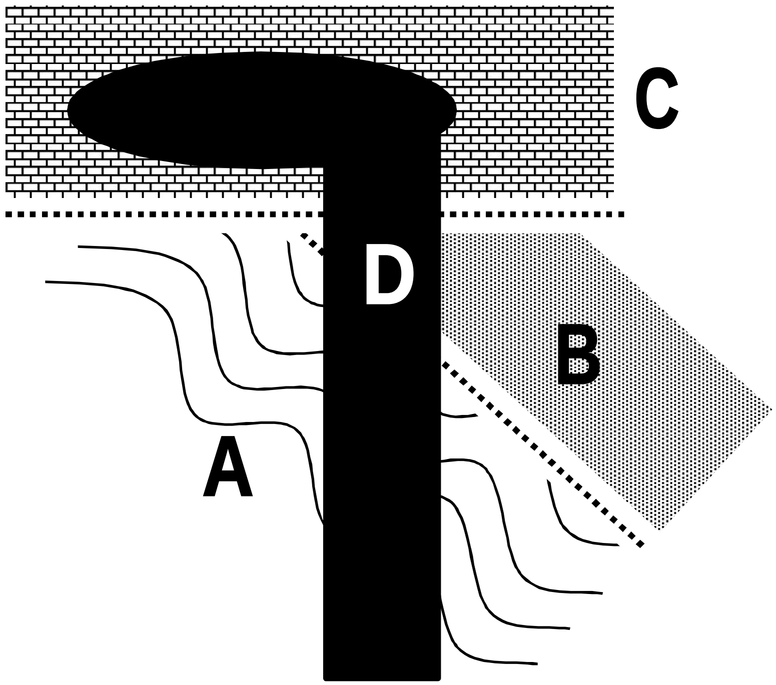
Other cross-cutting relationships



Igneous intrusions

- **volcano**

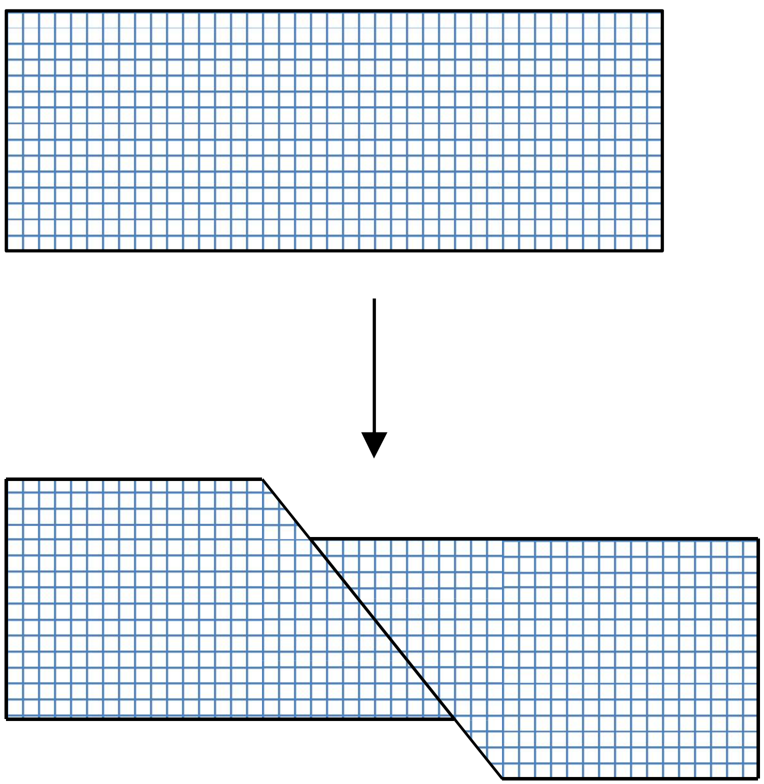
Other cross-cutting relationships



- **Igneous pluton**

- **D is the youngest**
- **A is the oldest**

Other cross-cutting relationships



- Fault movement causing an earthquake

Next!

- How do we determine how old a rock is?

Review

- Steno's rules
  - Principle of horizontality
  - Principle of lateral continuity
  - Principle of superposition
  - Principle of cross-cutting relationships
  - UMass Boston (https://youtu.be/Rsfq0zIOSdw)

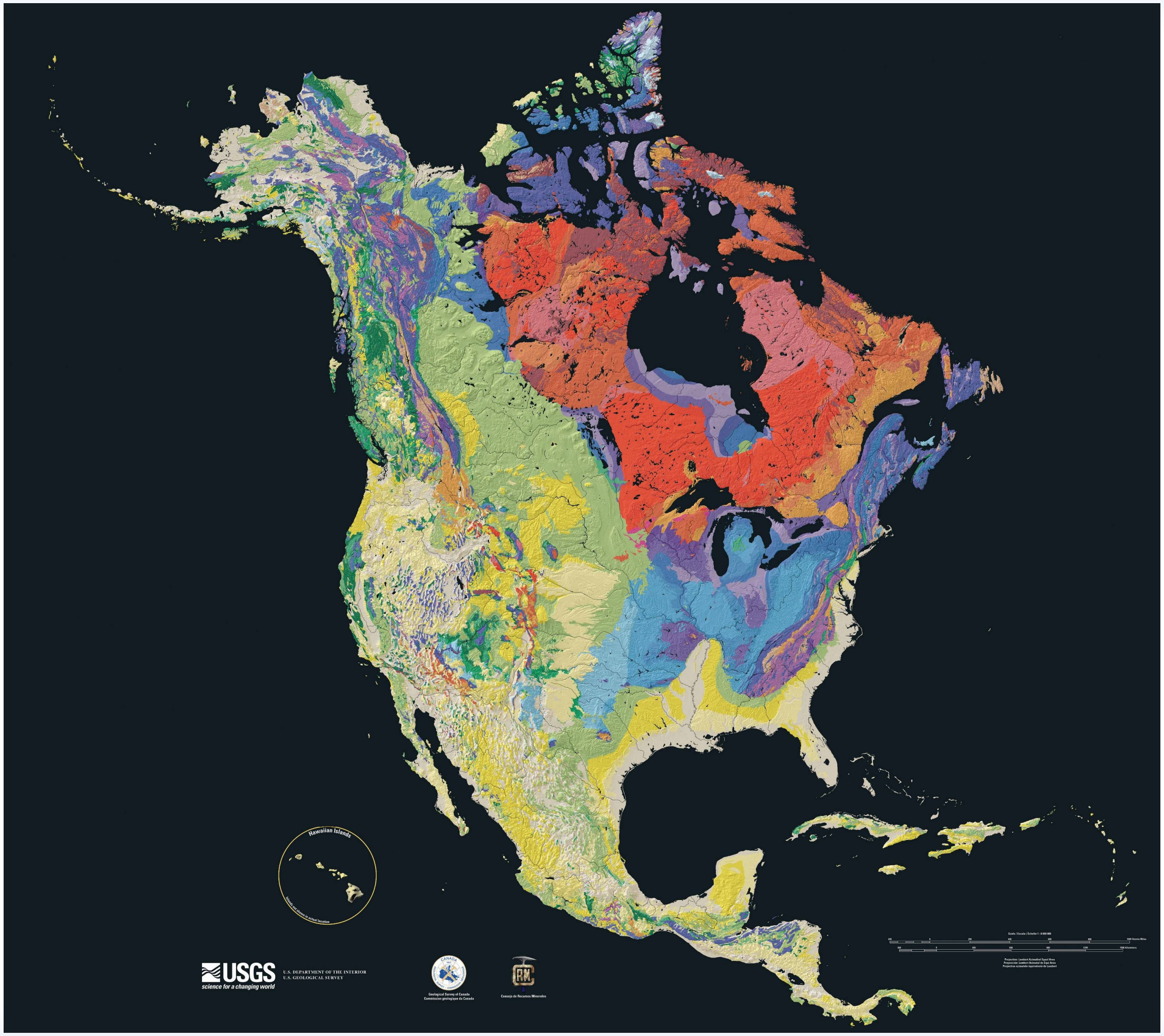
Objectives

- To understand the difference between relative and absolute geological dating
- To understand the principles behind radiometric dating
- To know what happened in Canada during the different eons and eras of geological time, and during the Quaternary period

Contents

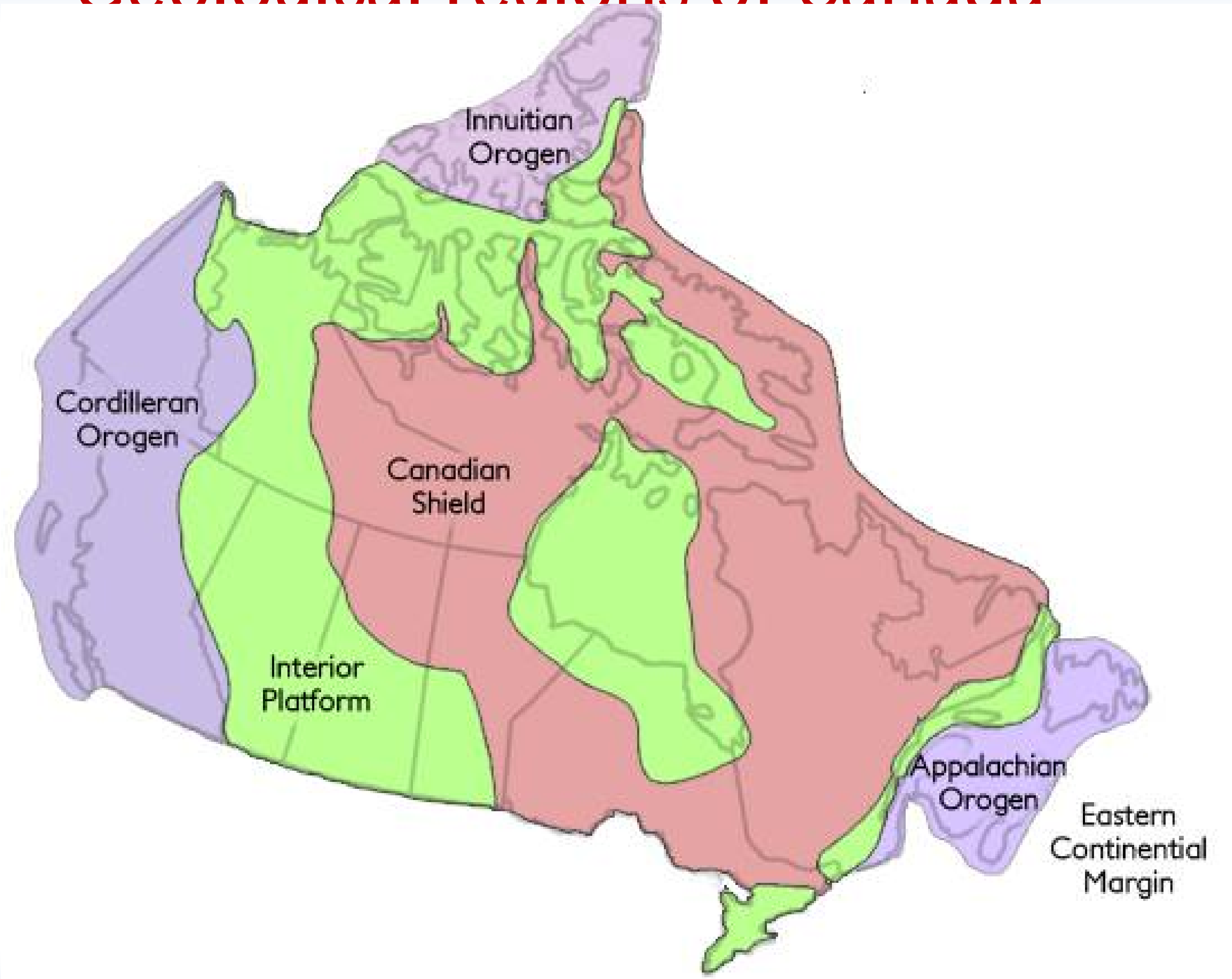
- Geological time scale
- Fossil record
- Relative dating
- Absolute dating

Geology of North America



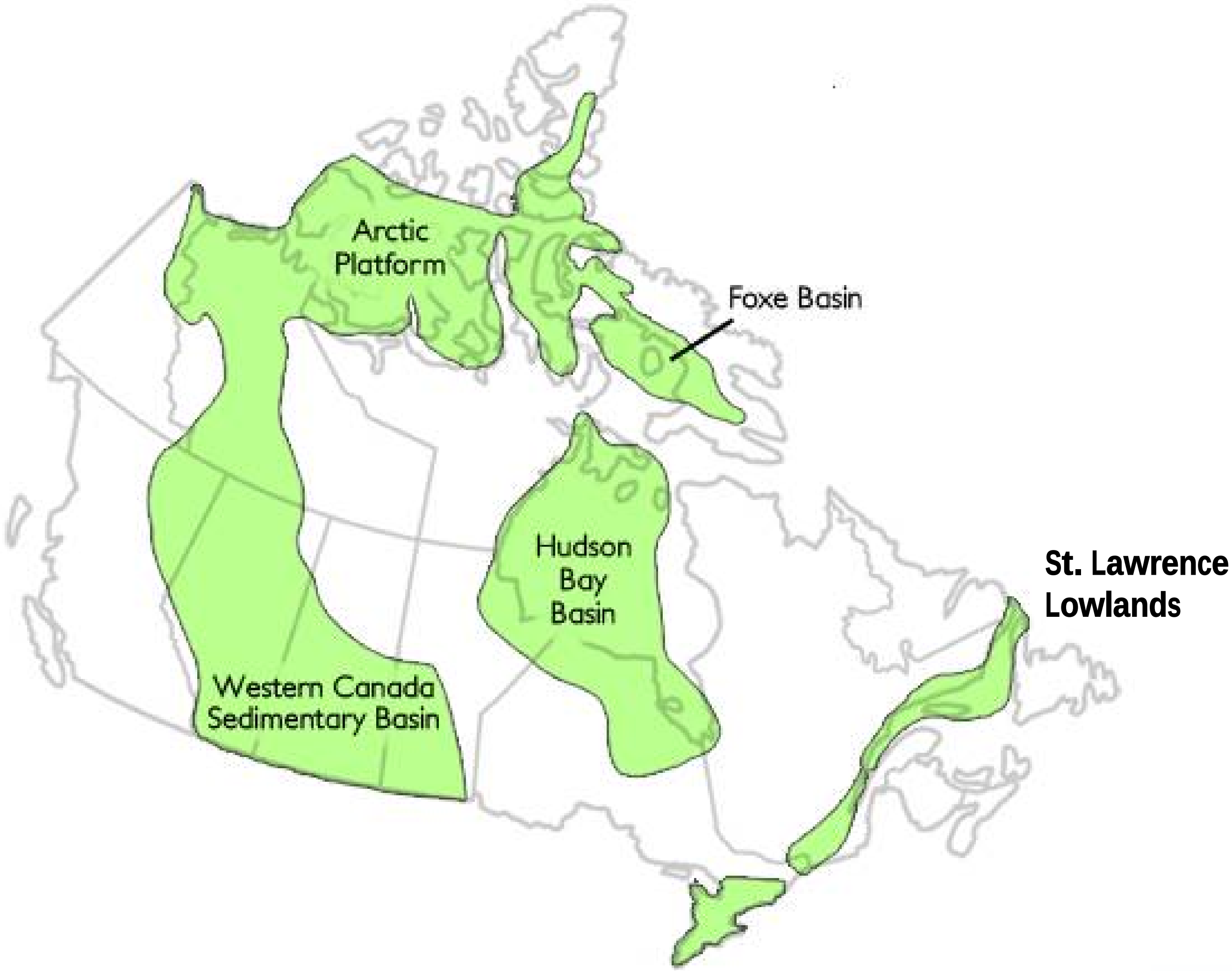
Source: GSC - USGS

Geological regions of Canada



Source: The Canadian Encyclopedia

Canadian Shield

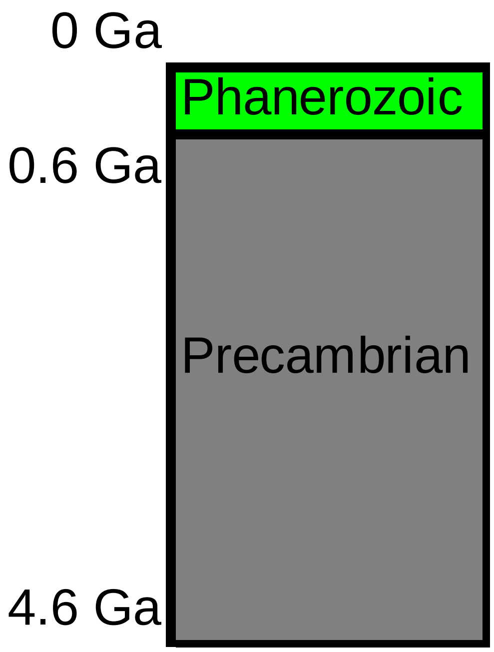

Arctic Platform
Foxe Basin
Hudson Bay Basin
St. Lawrence Lowlands
Western Canada Sedimentary Basin

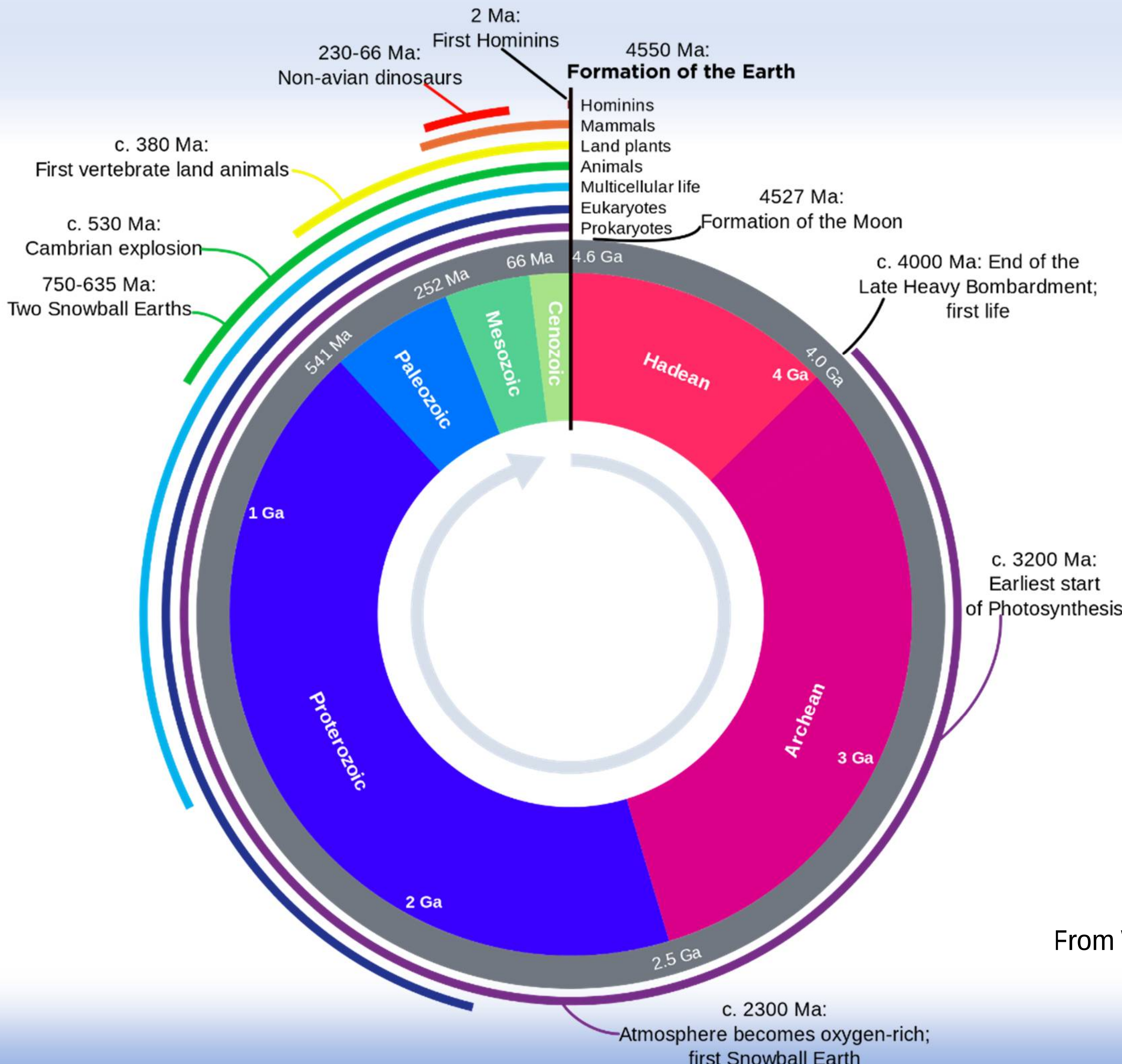
Appalachians

Cordillera

Eons

- **Eons**: largest divisions in geological time scale
  - Precambrian (Hadean, Archean, Proterozoic)
  - Phanerozoic





From Wikimedia Commons

Precambrian eon

- **Precambrian** (4.6 – 0.57 Ga; Hadean, Archean, Proterozoic)
  - ≈ 90% of Earth history
  - Scarce fossil record (soft-bodied life)
  - Rocks outcrops or are buried beneath younger rocks or surficial deposits
  - In Canada: very extensive Precambrian cover of major economic importance: “Canadian Shield”

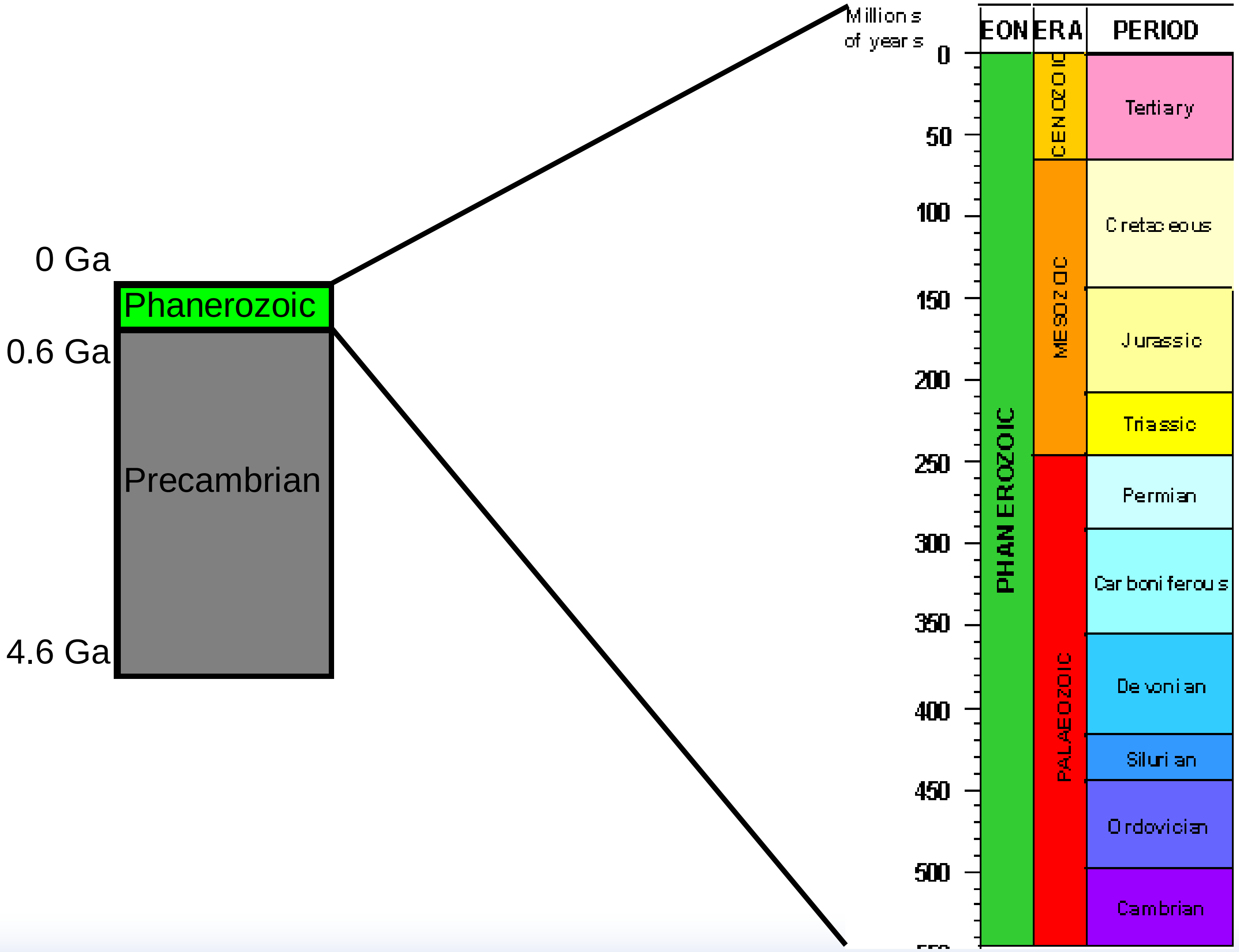
Canadian Shield

From Wikimedia Commons

Phanerozoic Eon

- Phanerozoic (> 0.57 Ga old)
  - Greek for “visible life”
  - Life on Earth abundant and diverse, as recorded by fossils
- Eons are split into **eras**
  - There are 3 Phanerozoic eras
- Eras split into **periods**

Phanerozoic eon

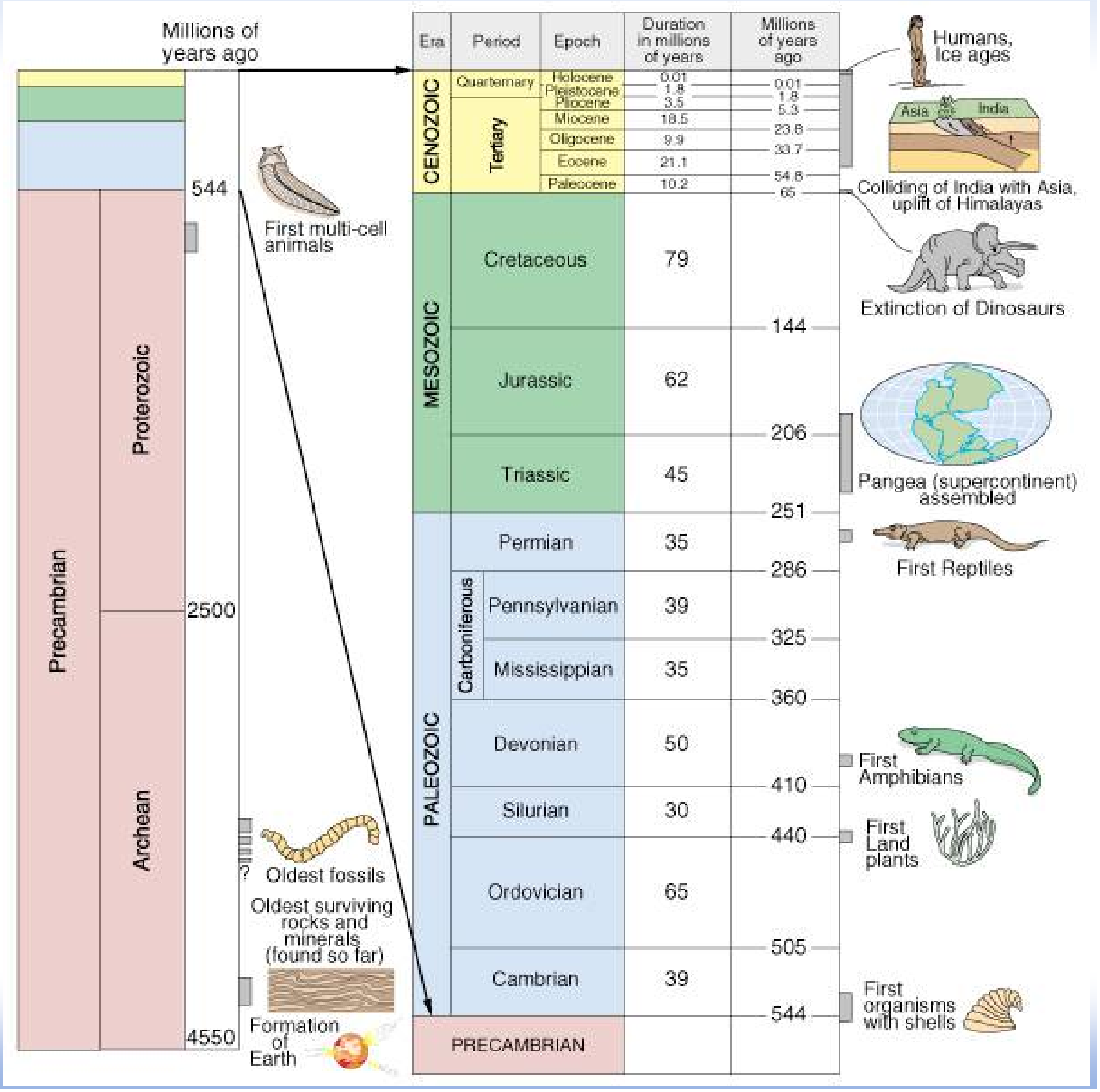


Phanerozoic Divisions

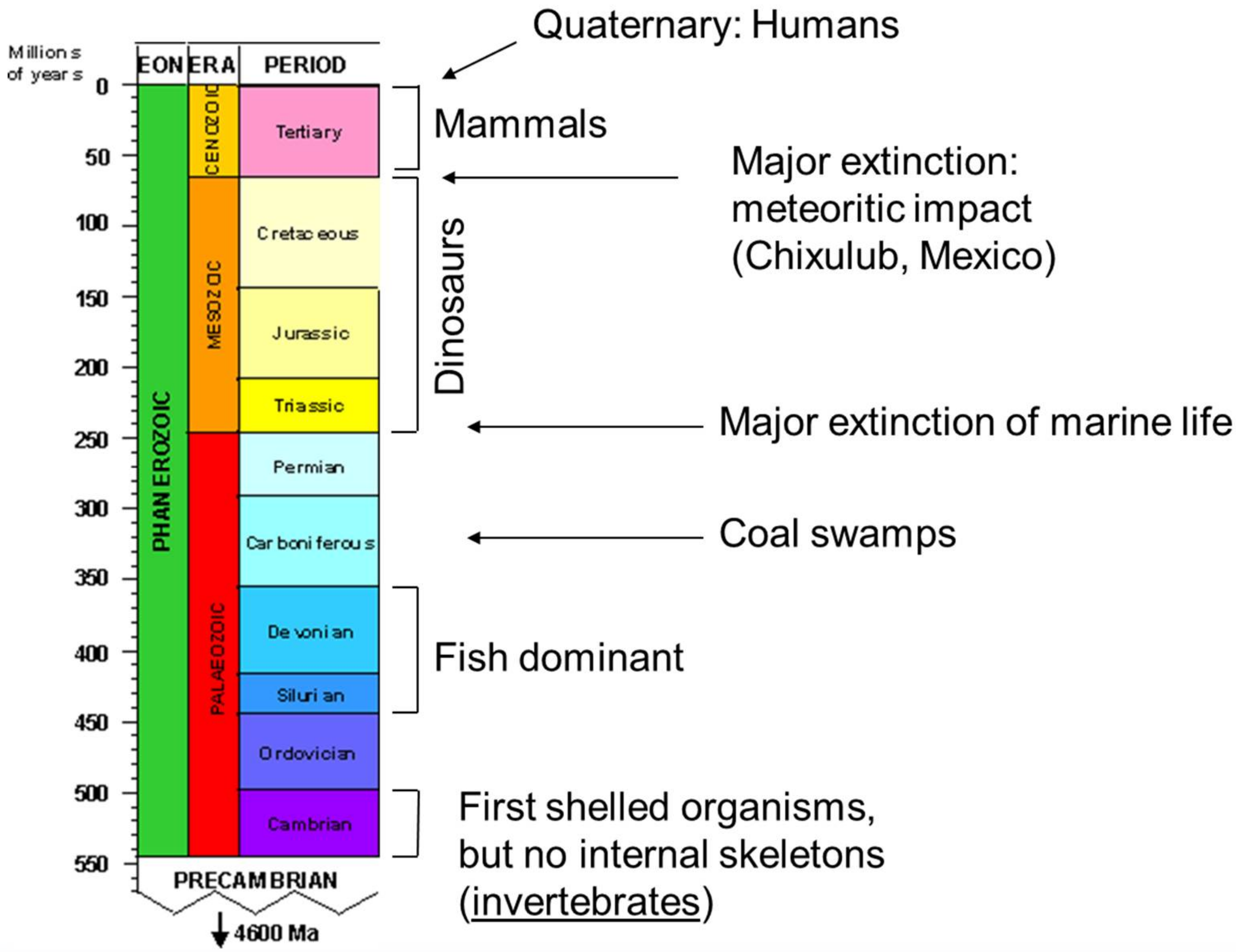
- **Cenozoic** (60 million years ago to present)
  - "Modern Life"
- **Mesozoic** (250-60 million years ago)
  - "Middle Life"
- **Paleozoic** (550 - 250 million years ago)
  - "Early Life"

The Phanerozoic

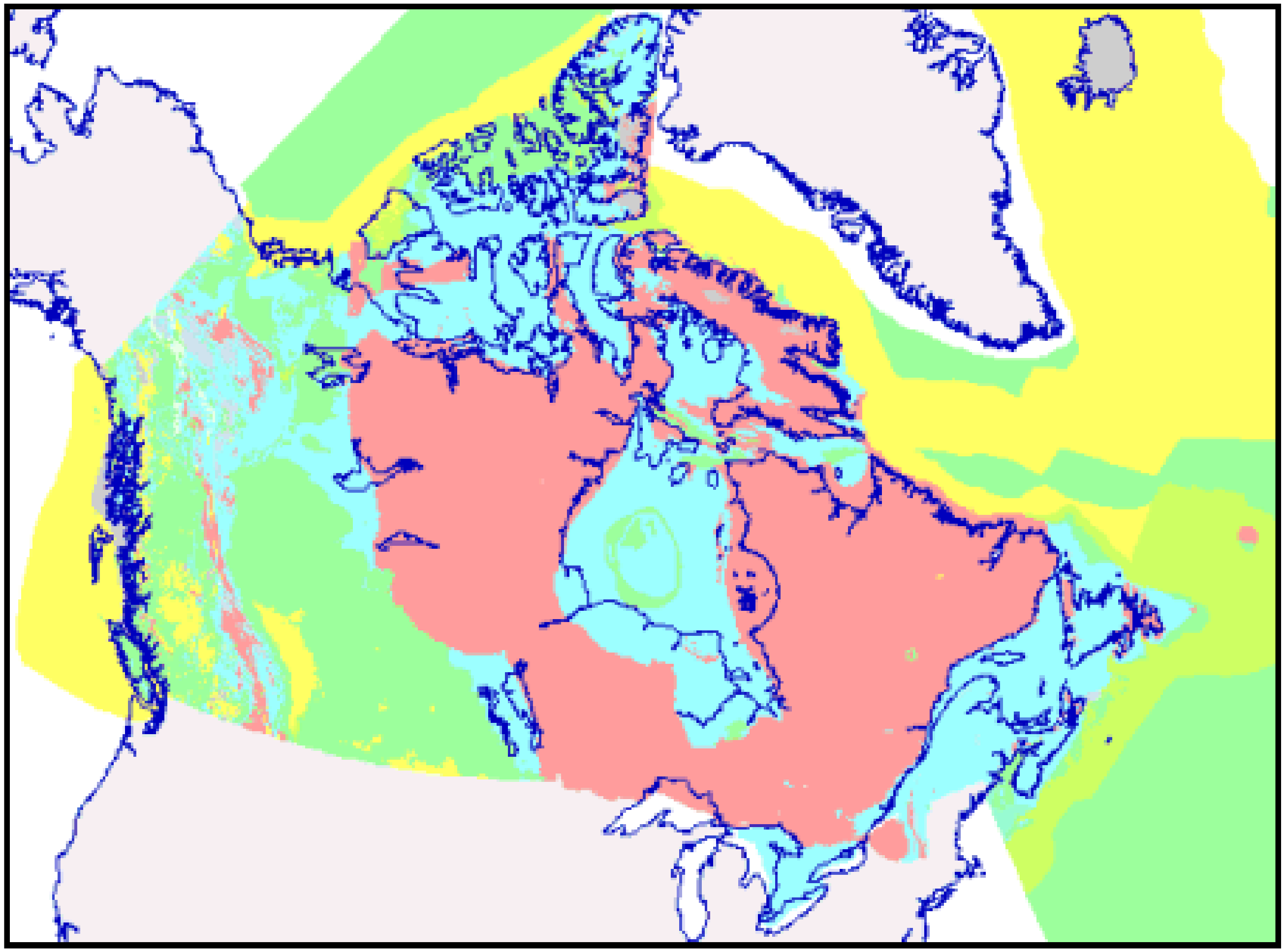
- Eons,
- Eras
- Periods
- Epochs



Phanerozoic Divisions



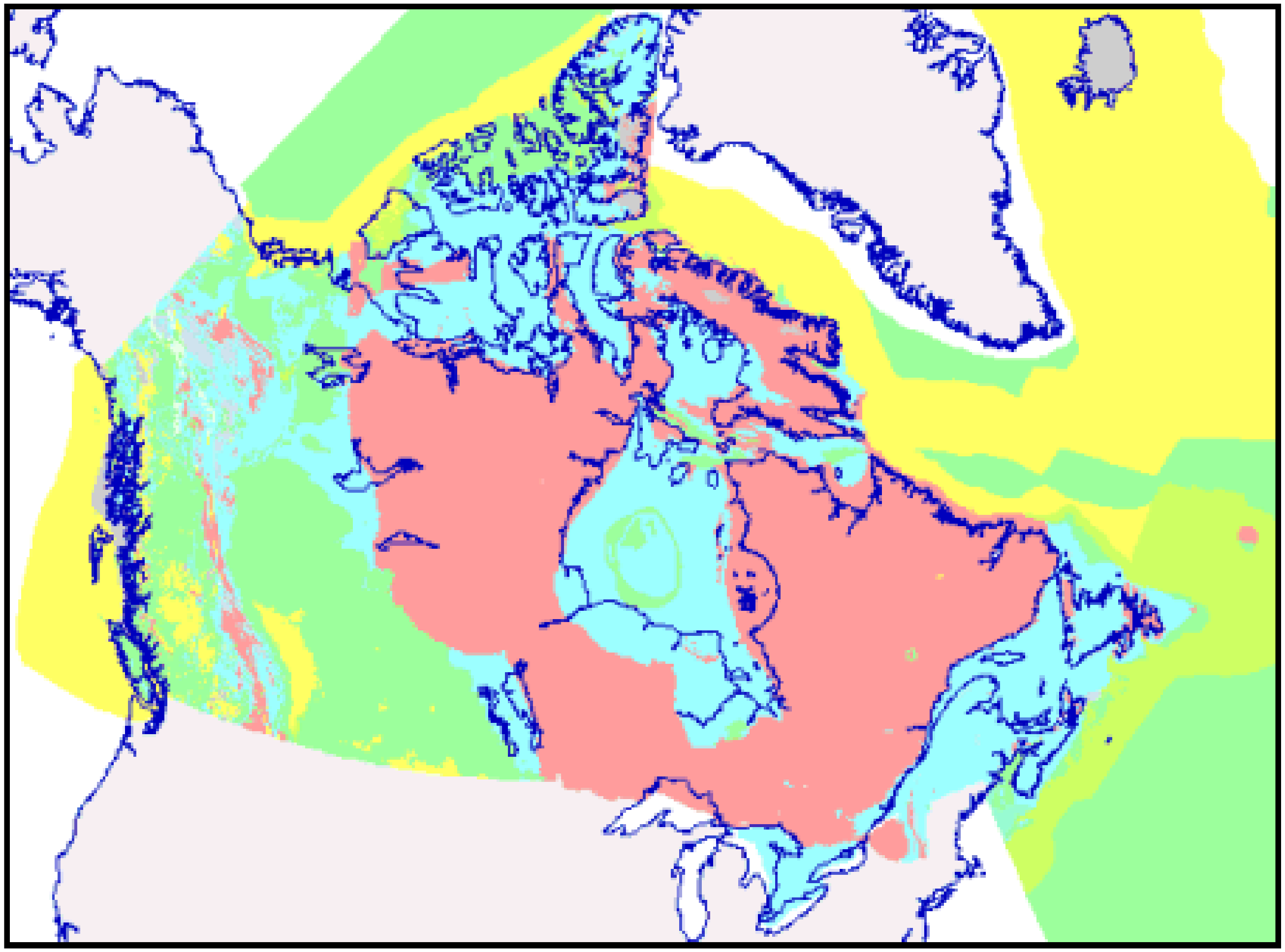
Phanerozoic Era: Paleozoic



Source: Natural Resources Canada (NRCan)

Paleozoic: Large parts of Canada covered by shallow seas

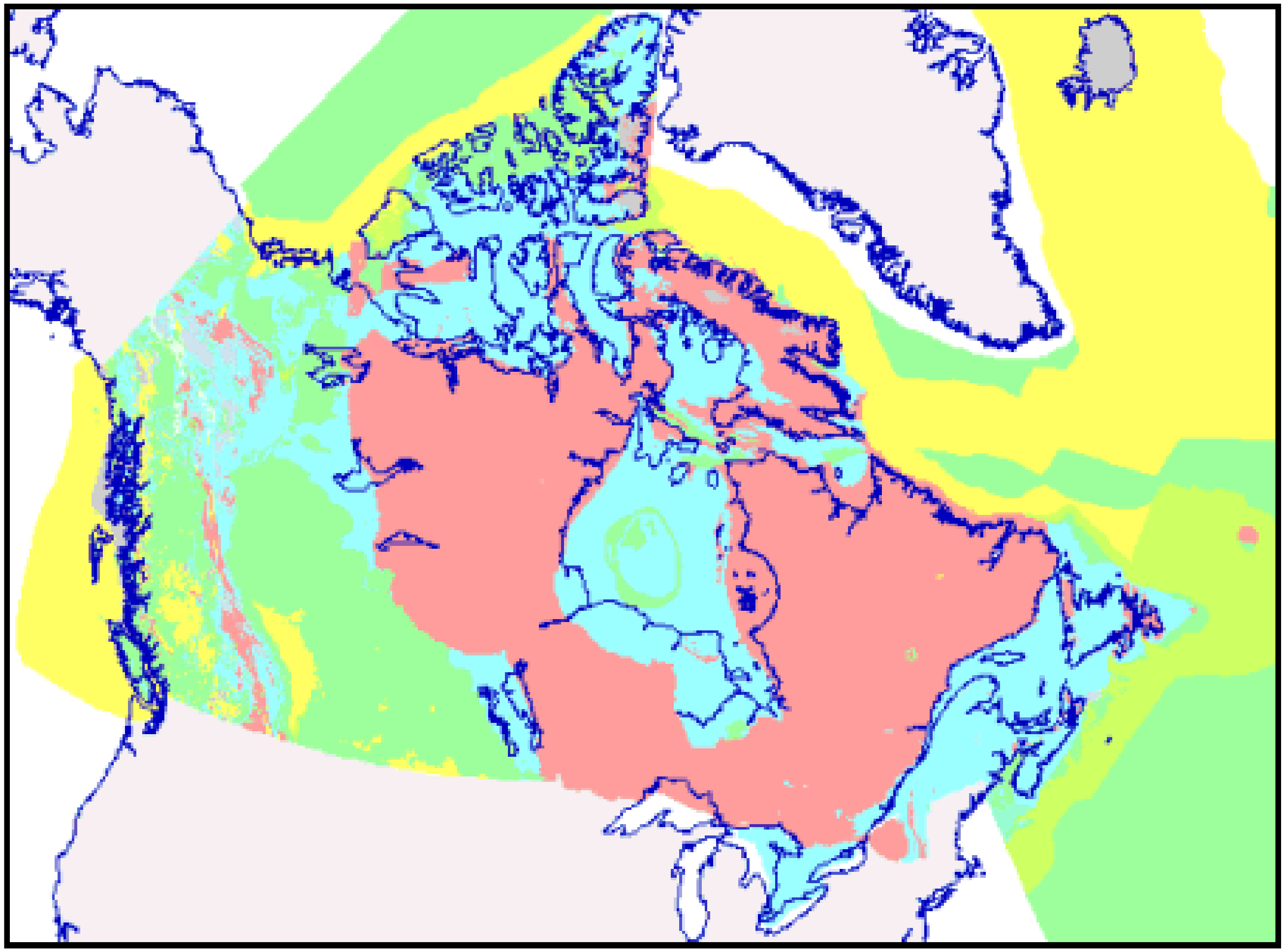
Phanerozoic Era: Mesozoic



Source: Natural Resources Canada (NRCan)

Mesozoic: formation of the Canadian Cordillera and central plains

Phanerozoic Era: Cenozoic



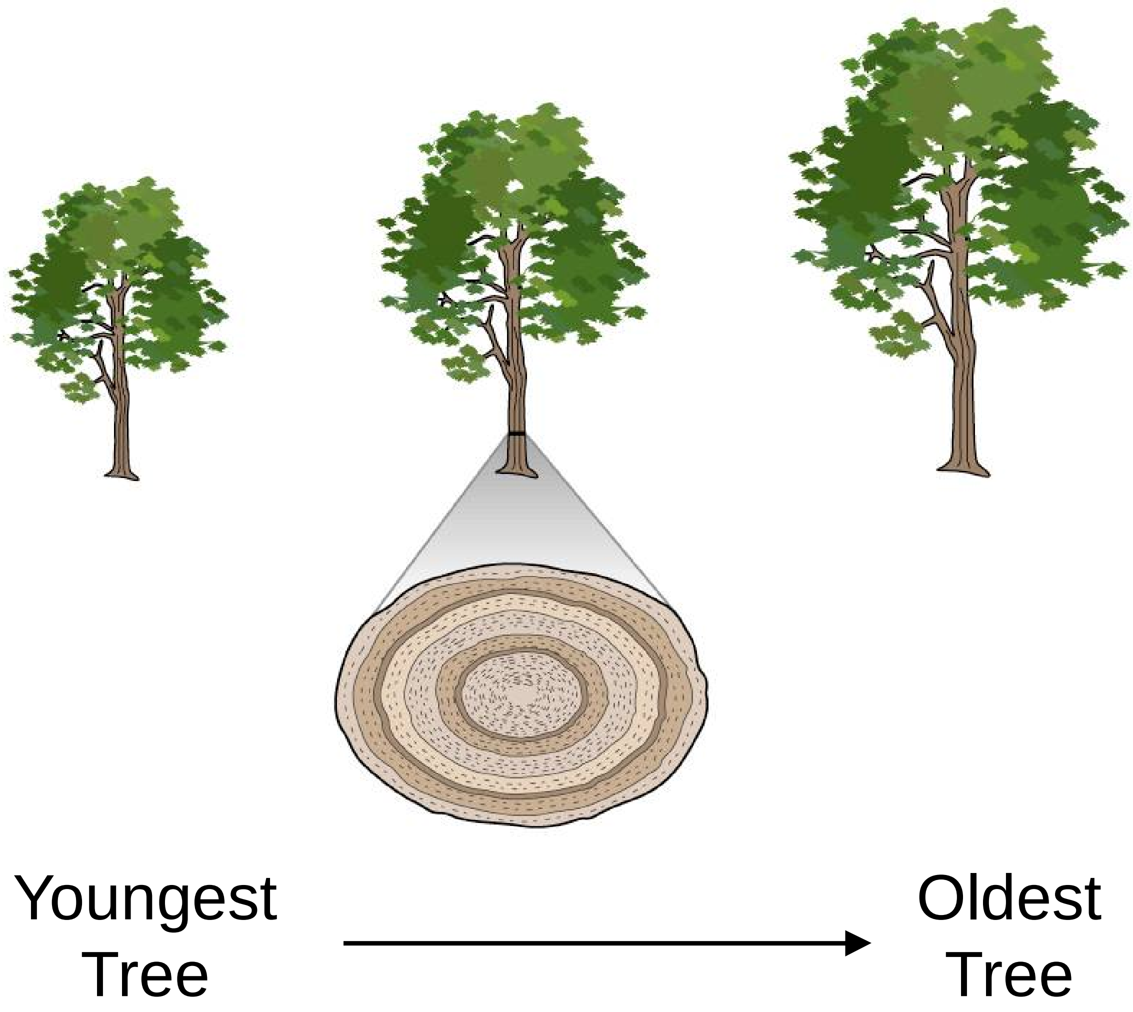
Cenozoic: sea floor spreading (east); subduction (west)

Quaternary period

- Quaternary period, evolution of humans
- Split in 2 epochs
  - Holocene (10,000 years ago to Present)
    - Epoch since last glaciation
  - Pleistocene (1.6 Ma to 10,000 years ago)
    - Epoch of many glaciations

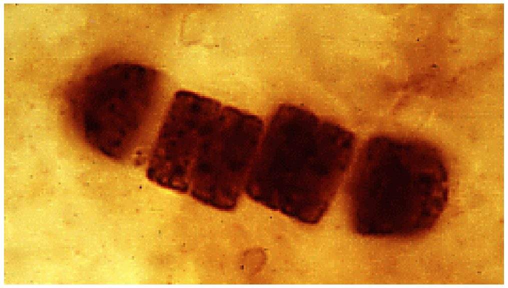
- During the Quaternary, most of Canada was covered under ice (glaciers) during multiple episodes

Relative vs Absolute dating

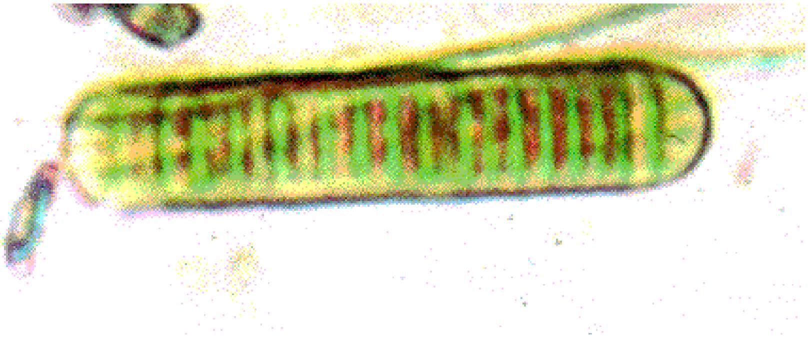


Fossil record

- First Fossils: Cyanobacteria
  - Single cell organisms
  - blue-green algae
  - Potentially 3.5 billion years old!



Fossil
1 billion years old



Modern

Stromatolites

- **Stromatolites**: Laminar, concentric structures
  - Pre-Cambrian
  - Blue-green algae secrete mucus, stick particles, build mats
  - Grow upwards in layers

Shark Bay,
NW Australia

Stromatolite Fossils

- Precambrian stromatolite fossils in Ottawa!

Ediacaran Fauna

- Oldest metazoans - 610 - 510 million years old; first locality in Ediacaran Hills, Australia
- Multi-cell organisms
- No skeletons, soft-bodied; resembled sea pens or jellys, stromatolites decline due to grazing

Pre-Cambrian

The“Cambrian Explosion”

- First appearance of “hard parts” 550 million years ago (Phanerozoic)
- View of life ~ 540 million years ago: Burgess Shale, B.C.

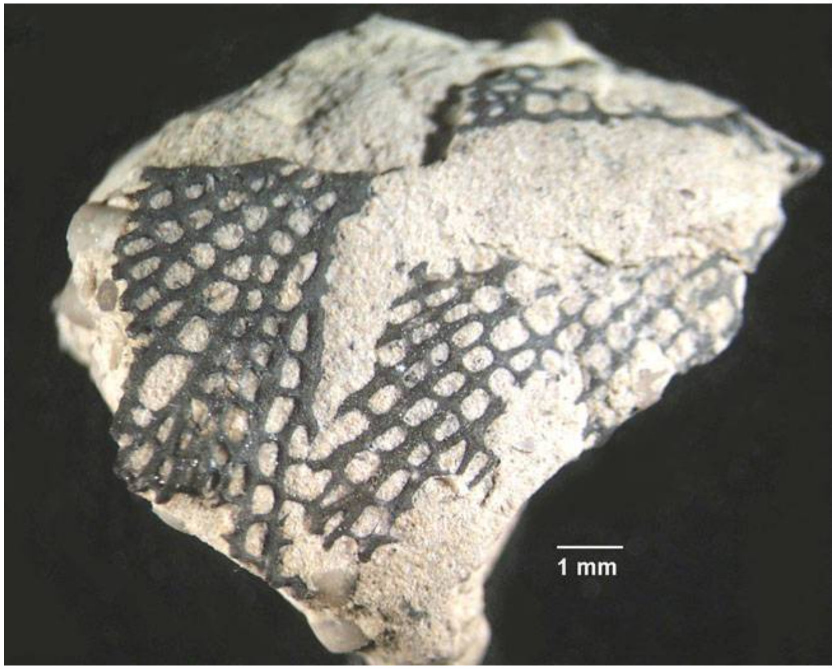
Source: Royal Tyrrell Museum; Government of Alberta

Phanerozoic Stage 1: Marine Organisms

- Marine crawlers and filter feeders
- Sponges: formed of rods or spicules; SiO_2
- Corals: sea anemones, sea fans, jellyfish: all stingers, secrete $CaCO_3$

Stage 1 (continued)

- Bryozoa: colonies of minute animals
- Twig-like shapes, pin-hole texture
- Secrete $CaCO_3$



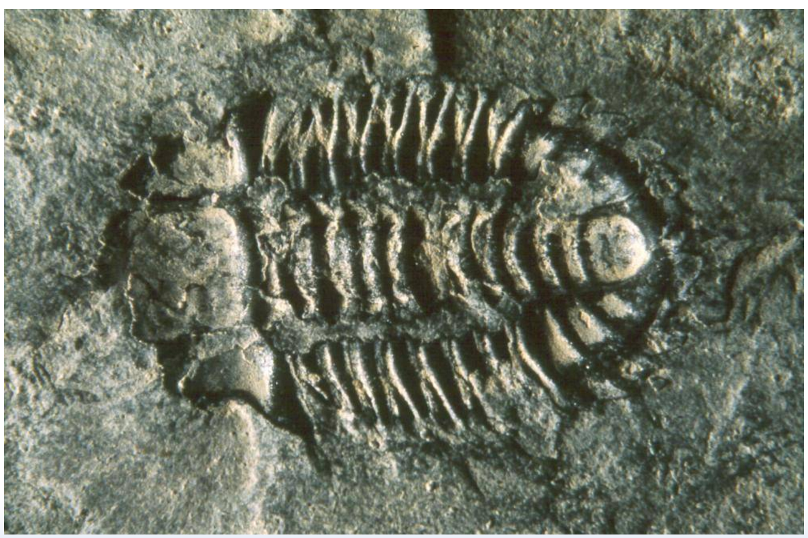
Stage 1 (continued)

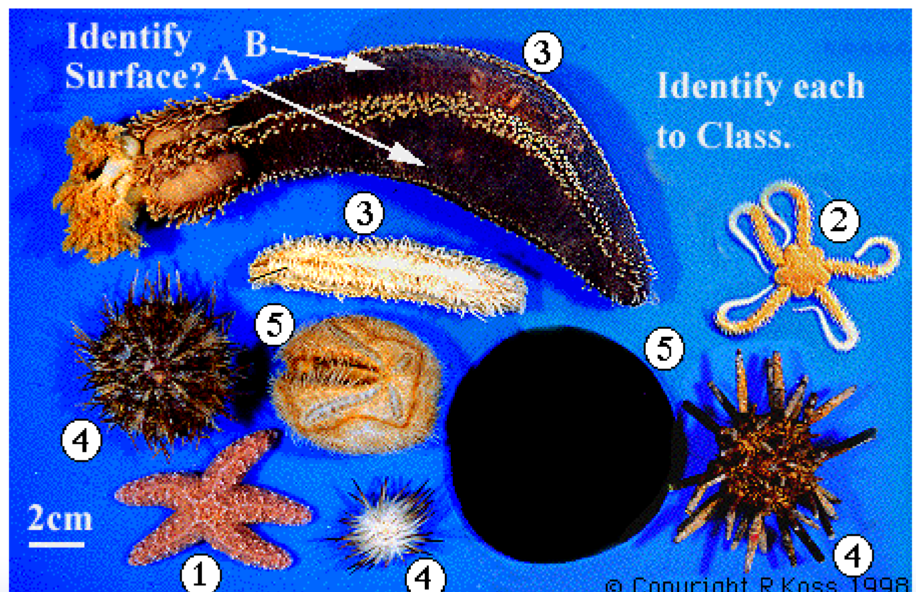
- Brachiopods: two shells, plane of symmetry down middle of shell; $CaCO_3$

- Mollusks: snails, clams, oysters, mussels; curved or coiled shells; $CaCO_3$

Stage 1 (continued)

- Trilobite: type of arthropod, three segments, compound eyes; $CaCO_3$
- Echinoderms: spiny-skinned; sea urchins, starfish, crinoids; $CaCO_3$

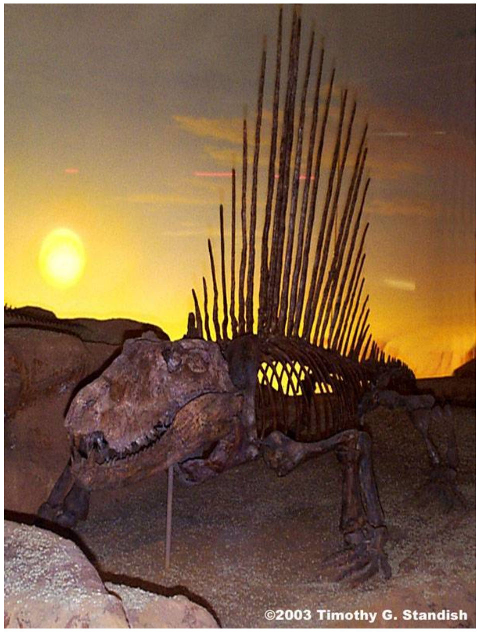




Phanerozoic Stage 2: Fish

- First internal skeletons observed in fish

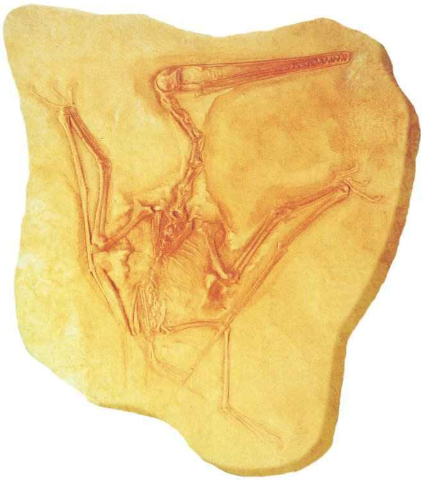
Phanerozoic Stage 3



- Life moves onland: first amphibians, land plants
- Amphibians: fish develop webbed feet; required more efficient heart, lungs to survive onland
- Still needed shallow seas, swampy shores

Phanerozoic Stage 4: Age of Reptiles

- Salamanders, dinosaurs
- Reptiles dominated the planet: air, land and sea



Phanerozoic Stage 4: Age of Reptiles

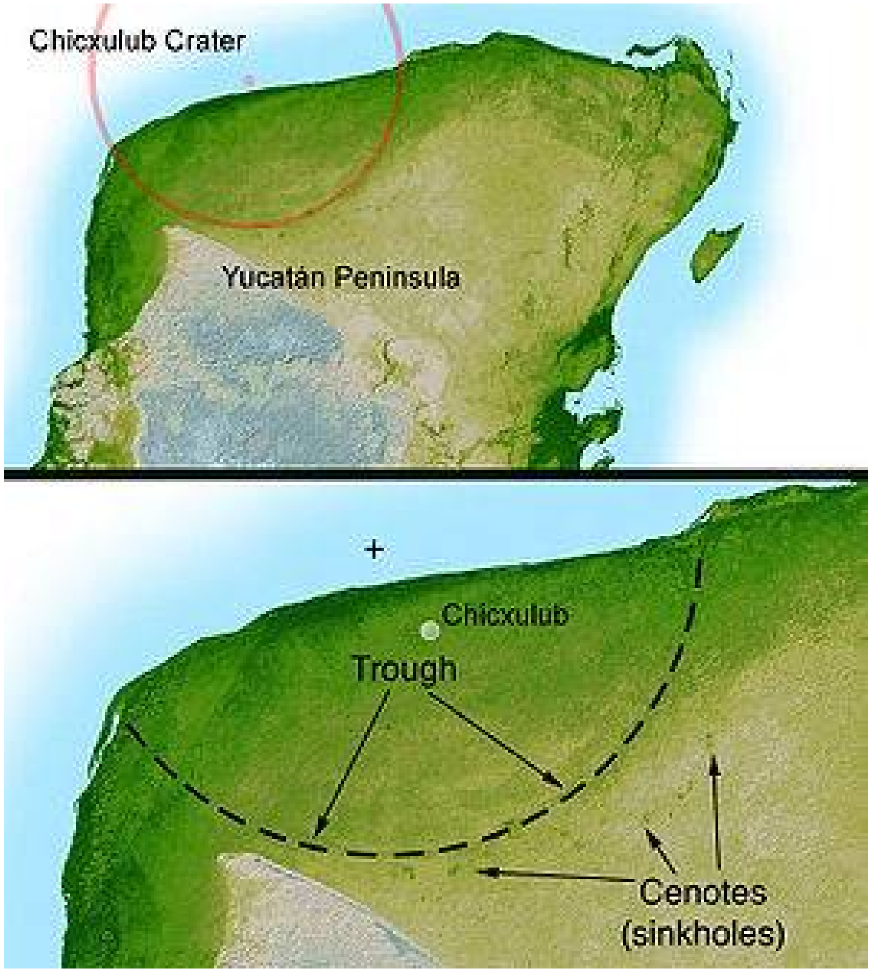
- How did dinosaurs go extinct?
- BBC Asteroid Attack
  - Part 1: https://youtu.be/JqGphEaJvDE
  - Part 2: https://youtu.be/rKwbuWN9R1c

Phanerozoic Stage 4: Age of Reptiles

- K-T boundary
  - Transition between Cretaceous to Tertiary periods
  - Now known as K-Pg boundary (Paleogene)
- Major extinction of reptiles, phytoplankton, mollusks at 60 million years ago
- Due to asteroid impact
  - High iridium concentrations found in strata

Phanerozoic Stage 4: Age of Reptiles

- Chicxulub crater of Mexico
- 180 km diameter



Phanerozoic Stage 5: Age of Mammals

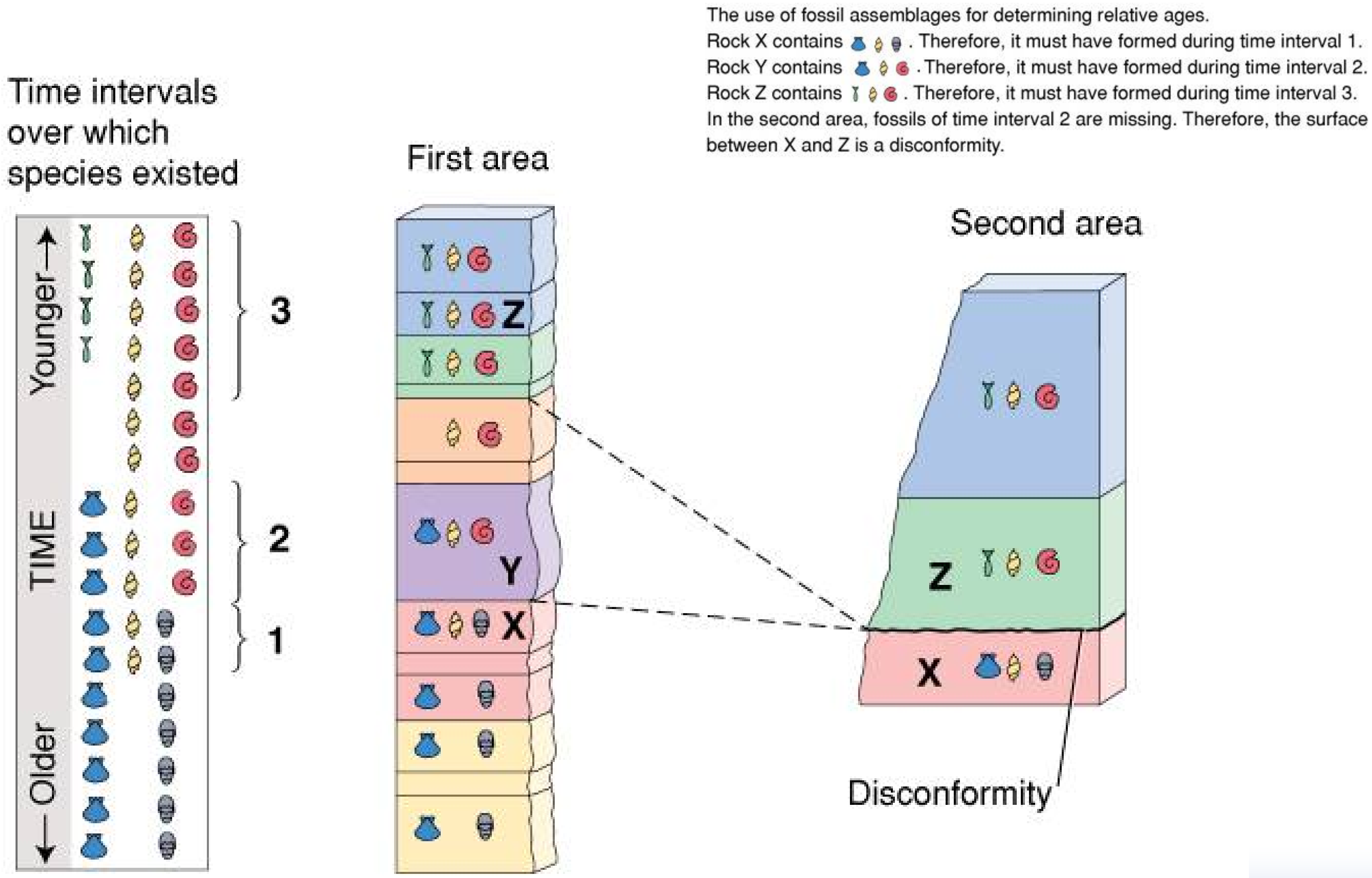
- Corals, bryozoa, some mollusks, brachiopods survive, flourish
- Fish, some amphibians, small reptiles survive; birds; mammals flourish

Biostratigraphy - Fossil Correlations

- Biostratigraphy helps us to determine the relative age between strata

- **Index fossil**: fossils used to identify specific geological periods

Biostratigraphy - Fossil Correlations



Relative vs Absolute dating

- General Rule: from biostratigraphy, we know the relative ages of rocks and fossils

- Problem
  - But still can’t say how old they are in absolute age.
  - How can we put real dates in the previous figure?

Absolute dating

- Answer: **radiometric dating**
  - Dating based on the decay of natural radioactive elements
  - From “parent” to “daughter” **isotope**

- **Absolute dating**: assigning a date to a rock unit

Absolute geological dating

- Planet Earth is 4.6 billion years (**Ga**) old
  - World oldest rock (4.055 Ga) found in NWT
  - No rock record between ≈ 4.0-4.6 Ga
    Early crust being recycled
- Geological dating
  - Before 1900: relative dating
  - Since 1900: absolute **radiometric dating**

How Carbon Dating Works

- This movie is about C_{14} but the same idea applies to other radioactive isotopes
- https://www.youtube.com/watch?v=Kcuz1JiMk9k

Radioactive decay

- Age is determined by the parent/daughter isotope ratio
  - Number of parent atoms decay exponentially with time

    $N = N_0 e^{-\lambda t}$

Where	N:	number of atoms at time t
	N_0:	number of atoms at time t=0
	λ:	decay constant [time-1]

Radioactive decay

- **Half-life** ($t_{1/2}$): time required for half of the atoms of the parent element to decay to a daughter element

  - Number of parent atoms decay exponentially with time

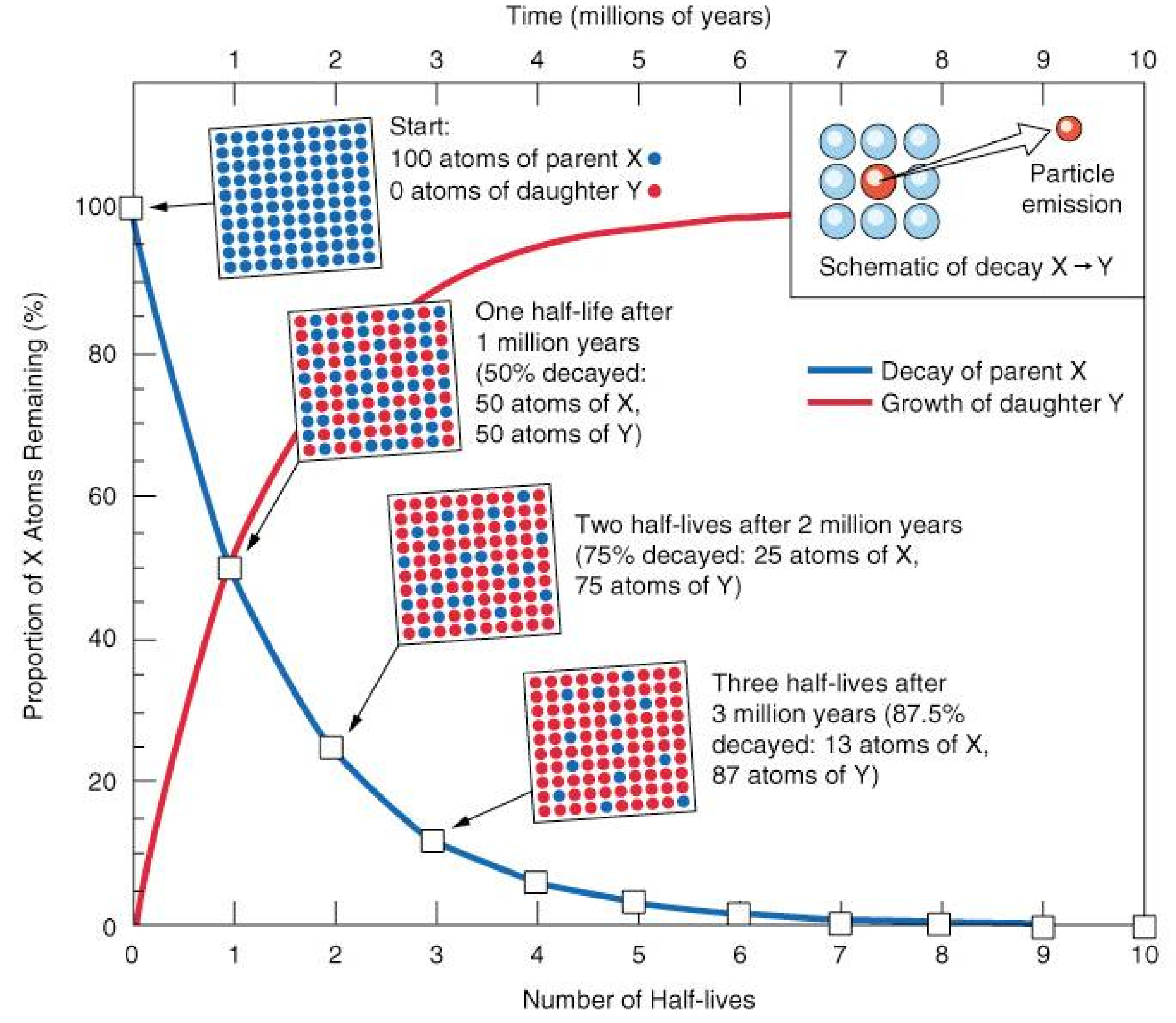
$N_0 / 2 = N_0 e^{-\lambda\, t1/2}$

$\ln(1/2) = -\lambda\, t1/2$

$1/\lambda \ln(2) = t1/2$

note: $\ln(1/2) = -1 \ln(2)$

Radioactive decay



Radiometric dating

- Choose parent/daughter pair in relation to the length of time to be measured

Parent	Daughter	Half-life
Rubidium 87	Strontium 87	48.8 Ga
Uranium 238	Lead 206	4.47 Ga
Potassium 40	Argon 40	1.3 Ga
Uranium 235	Lead 207	704 Ma
Carbon 14	Nitrogen 14	5730 years

Radioactive dating

- Critical assumption of a "Closed system":
  - The "clock" was set to zero when the study material was formed
    - Only the parent isotope is initially present – OR –
    - The amount of daughter isotope present at the beginning is known and can be subtracted
  - No loss or addition of either parent or daughter elements has occurred since the study material formed

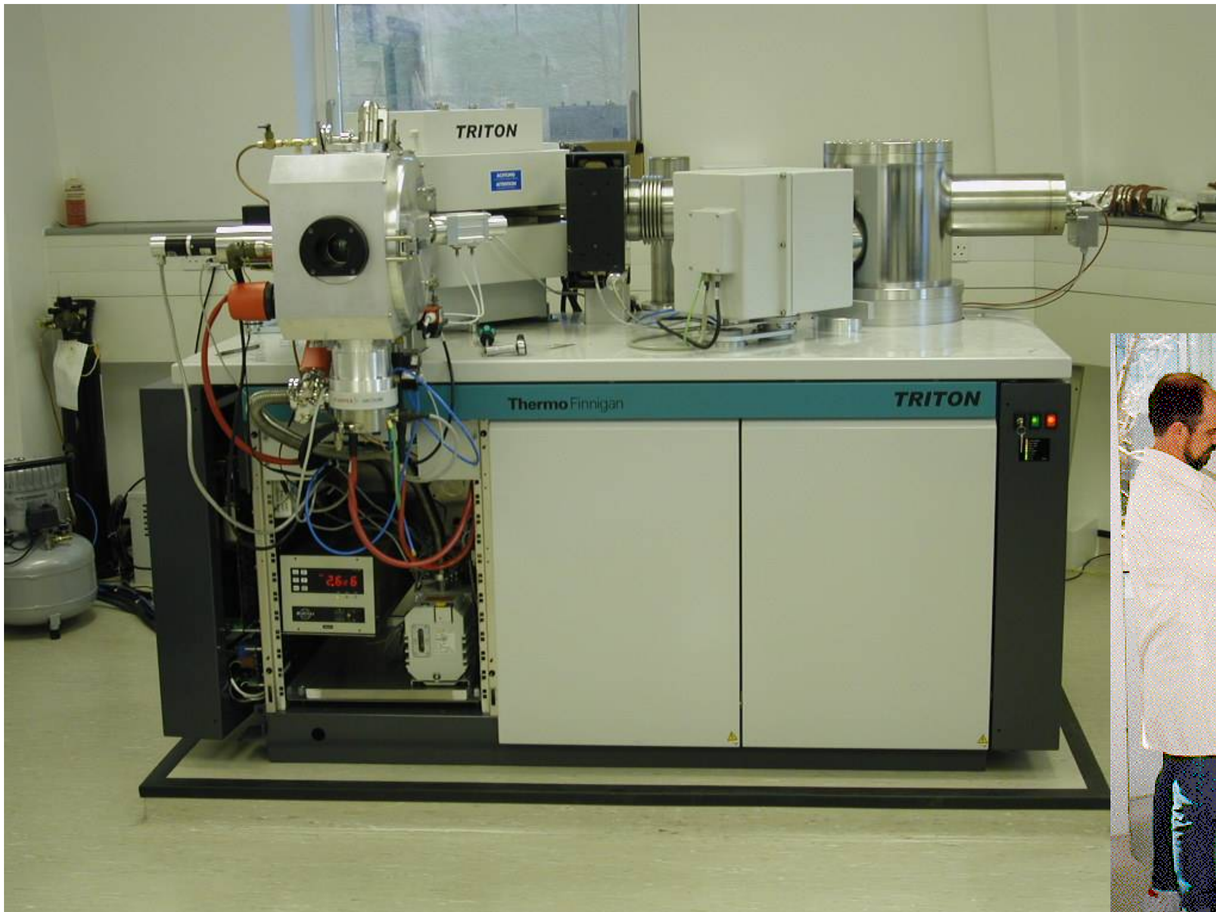
Radioactive dating

The length of time over which decay has been occurring:

$$t = (1/\lambda) \ln(1 + D/P)$$

t:	age of specimen	[year]	
λ:	decay constant	[year $^{-1}$]	KNOWN
D:	number of atoms of the daughter element		MEASURED
P:	number of atoms of the parent element		MEASURED

Instruments



Mass Spectrometer

Example

- Typically performed on a mineral that is resistant to diffusion of isotopes
  - Uranium-lead dating using ZIRCON ($ZrSiO_4$)

- An example: the U-Pb system

$$t = (1/\lambda) \ln(1 + t/p)$$

$$t = (1/\lambda) * \ln[(^{206}Pb_p - {}^{206}Pb_t)/ {}^{238}U_p + 1]$$

where λ = decay constant (= $0.693/t^{1/2}$)

p = present day (daughter)

t = time of crystallization (parent)

Zircon

- **Only** crystallizes in **continental rocks**
- Can use ages of zircons to outline the history of continental growth through time

Next Lecture: Minerals!