Precambrian Earth and Life History—The Hadean and Archean
If a single day represented all 4.6 billion years of geologic time

- the Precambrian would be slightly more than 21 hours long,
- It constitutes about 88% of all geologic time
The term **Precambrian** is an informal term referring to both time and rocks.

- It includes time from Earth’s origin 4.6 billion years ago to the beginning of the Phanerozoic Eon 545 million years ago.
- No rocks are known for the first 640 million years of geologic time.
  - The oldest known rocks on Earth are 3.96 billion years old.
Rocks of the Precambrian

The earliest record of geologic time preserved in rocks is difficult to interpret because many Precambrian rocks have been

- complexly deformed and metamorphosed
- buried deep beneath younger rocks
- fossils are rare

Because of this subdivisions of the Precambrian have been difficult to establish

The Precambrian consists of two eons: the **Archean** and **Proterozoic**
Eons of the Precambrian

The Hadean is an informal designation for the time preceding the Archean Eon

- Represents the formative period of Earth history
- The onset of the Archean Eon coincides with the age of Earth’s oldest known rocks

approximately 4 billion years old
lasted until 2.5 billion years ago (the beginning of the Proterozoic Eon)
The Hadean?

Except for meteorites no rocks of Hadean age are present on Earth, however we do know some events that took place during this period:

- Earth was accreted
- Differentiation occurred, creating a core and mantle and at least some crust
Oldest Rocks: The onset of the Archean

Judging from the oldest known rocks on Earth, the 3.96-billion-year-old Acasta Gneiss in Canada some continental crust had evolved by 4 billion years ago.

- Sedimentary rocks in Australia contain detrital zircons (ZrSiO$_4$) dated at 4.2 billion years old.
- These rocks indicted that some kind of Hadean crust was certainly present, but its distribution is unknown.
Early Hadean crust was probably thin, unstable and made up of ultramafic rock.

As Earth cooled more and more silica-rich rock would have erupted, replacing the early mafic crust with a sialic crust.

- Sialic crust contains considerable silicon, oxygen and aluminum as in present day continental crust.

- Only silica-rich crust, because of its lower density, is immune to destruction by subduction.
Continental Foundations

- Continents consist of rocks with composition similar to that of granite
  
  - **Precambrian shields** consist of vast areas of exposed ancient rocks and are found on all continents
  
  - Outward from the shields are broad **platforms** of buried Precambrian rocks that underlie much of each continent
Cratons

- A shield and platform make up a **craton**
  - a continent’s ancient nucleus and its foundations

- Along the margins of cratons, more continental crust was added as the continents took their present sizes and shapes

- Both Archean and Proterozoic rocks are present in cratons and show evidence of episodes of deformation accompanied by
  - Metamorphism
  - igneous activity
  - and mountain building

- Cratons have experienced little deformation since the Precambrian
Distribution of Precambrian Rocks

Areas of exposed Precambrian rocks constitute the shields
Platforms consist of buried Precambrian rocks

Shields and adjoining platforms make up cratons
Canadian Shield

The craton in North America is the Canadian shield

- Occupies most of northeastern Canada, a large part of Greenland, parts of the Lake Superior region in Minnesota, Wisconsin, Michigan, and the Adirondack Mountains of New York.

It’s topography is subdued, with numerous lakes and exposed Archean and Proterozoic rocks thinly covered in places by Pleistocene glacial deposits.
Canadian Shield Rocks

Gneiss, a metamorphic rock, Georgian Bay Ontario, Canada
Amalgamated Cratons

- The Canadian shield and adjacent platform consists of numerous units or smaller cratons that were **welded** together along **deformation belts** during the Early Proterozoic.
  - Absolute ages and structural trends help geologists differentiate among these various smaller cratons.
The most common Archean Rock associations are **granite-gneiss complexes**

**Greenstone belts** are subordinate in quantity but are important in unraveling Archean tectonism.
Greenstone Belts

▶ An ideal greenstone belt has 3 major rock units
  ▪ volcanic rocks are most common in the lower and middle units
  ▪ the upper units are mostly sedimentary

▶ The belts typically have synclinal structure
  ▪ Most were intruded by granitic magma and cut by thrust faults

▶ Low-grade metamorphism
  ▪ makes many of the igneous rocks greenish (chlorite)
Greenstone Belt Volcanics

- Abundant pillow lavas in greenstone belts

Pillow lavas in Ispheming greenstone at Marquette, Michigan
Ultramafic Lava Flows

- The most interesting rocks in greenstone belts cooled from ultramafic lava flows
- Ultramafic magma has less than 40% silica
  - Requires near surface magma temperatures of more than 1600°C—250°C
- During Earth’s early history, radiogenic heating was higher and the mantle was as much as 300 °C hotter than it is now
- This allowed ultramafic magma to reach the surface
Sedimentary Rocks of Greenstone Belts

- Sedimentary rocks are found throughout the greenstone belts
  - Mostly in the upper unit

- Many of these rocks are successions of graywacke and argillite, a slightly metamorphosed mudrock
Small-scale cross-bedding and graded bedding indicate an origin as turbidity current deposits.

- Quartz sandstone and shale, indicate delta, tidal-flat, barrier-island and shallow marine deposition.
Two adjacent greenstone belts showing synclinal structure.

They are underlain by granite-gneiss complexes and intruded by granite.
Canadian Greenstone Belts
In one model, plates formed volcanic arcs by subduction.

- The greenstone belts formed in back-arc marginal basins.
Evolution of Greenstone Belts

- Then during closure, the rocks were compressed, deformed, cut by faults, and intruded by rising magma.

- The Sea of Japan is a modern example of a back-arc basin.
Southern Superior Craton Evolution

Geologic map

Greenstone belts (dark green)
Granite-gneiss complexes (light green)
Archean Plate Tectonics

Plate tectonics occurred in the Archean just as today but since the Earth was hotter than today

- Plates must have moved faster
- Magma was generated more rapidly
Archean Plate Tectonics

As a result of the rapid movement of plates, continents, grew more rapidly along their margins

► this process is called **continental accretion**

► Also, ultramafic extrusive igneous rocks were more common due to the higher temperatures
Earth’s Very Early Atmosphere

- Earth’s very early atmosphere was probably composed of hydrogen and helium, the most abundant gases in the universe.

- If so, it would have quickly been lost into space because Earth’s gravity is insufficient to retain them.
  - Also because Earth had no magnetic field until its core formed, the solar wind would have swept away any atmospheric gases.
Present-day Atmosphere

Non-variable gases
Nitrogen (N₂) - 78.08%
Oxygen (O₂) - 20.95
Argon (Ar) - 0.93
Neon (Ne) - 0.002
Others - 0.001

in percentage by volume

Variable gases
Water vapor - 0.1 to 4.0
Carbon dioxide - 0.034
Ozone - 0.0006
Other gases - trace
Particulates - normally trace
Once a core-generated magnetic field protected Earth, gases released during volcanism began to accumulate

- Called **outgassing**

Water vapor is the most common volcanic gas today

- also emitted
  - carbon dioxide
  - sulfur dioxide
  - Hydrogen Sulfide
  - carbon monoxide
  - Hydrogen
  - Chlorine
  - nitrogen
Hadean-Archean Atmosphere

- Hadean volcanoes probably emitted the same gases, and thus an atmosphere developed.

- Atmosphere would be rich in carbon dioxide and other volcanic gases reacting in this early atmosphere probably formed:
  - ammonia (NH$_3$)
  - methane (CH$_4$)

- This early atmosphere persisted throughout the Archean.
Evidence for an Oxygen-Free Atmosphere

- The atmosphere was chemically reducing rather than an oxidizing one.

- Some of the evidence for this conclusion comes from detrital deposits containing minerals that oxidize rapidly in the presence of oxygen.
  - pyrite ($\text{FeS}_2$)

- Oxidized iron becomes increasingly common in Proterozoic rocks.
Introduction of Free Oxygen

Two processes account for introducing free oxygen into the atmosphere,

1. **Photochemical dissociation** involves ultraviolet radiation in the upper atmosphere
   - The radiation breaks up water molecules and releases oxygen and hydrogen
     - This could account for 2% of present-day oxygen
     - but with 2% oxygen, ozone forms, creating a barrier against ultraviolet radiation

2. More important were the activities of organism that practiced **photosynthesis**
Earth’s Surface Waters

- Outgassing was responsible for the early atmosphere and also for Earth’s surface water
  - the hydrosphere
    - Some but probably not much of our surface water was also derived from icy comets

- At some point during the Hadean, the Earth had cooled sufficiently so that the abundant volcanic water vapor condensed and began to accumulate in oceans
  - Oceans were present by Early Archean times
Today, Earth’s biosphere consists of millions of species of bacteria, fungi, protistans, plants, and animals.

- only bacteria are found in Archean rocks

We have fossils from Archean rocks

- 3.3 to 3.5 billion years old

Carbon isotope ratios in rocks in Greenland that are 3.85 billion years old convince some investigators that life was present then.