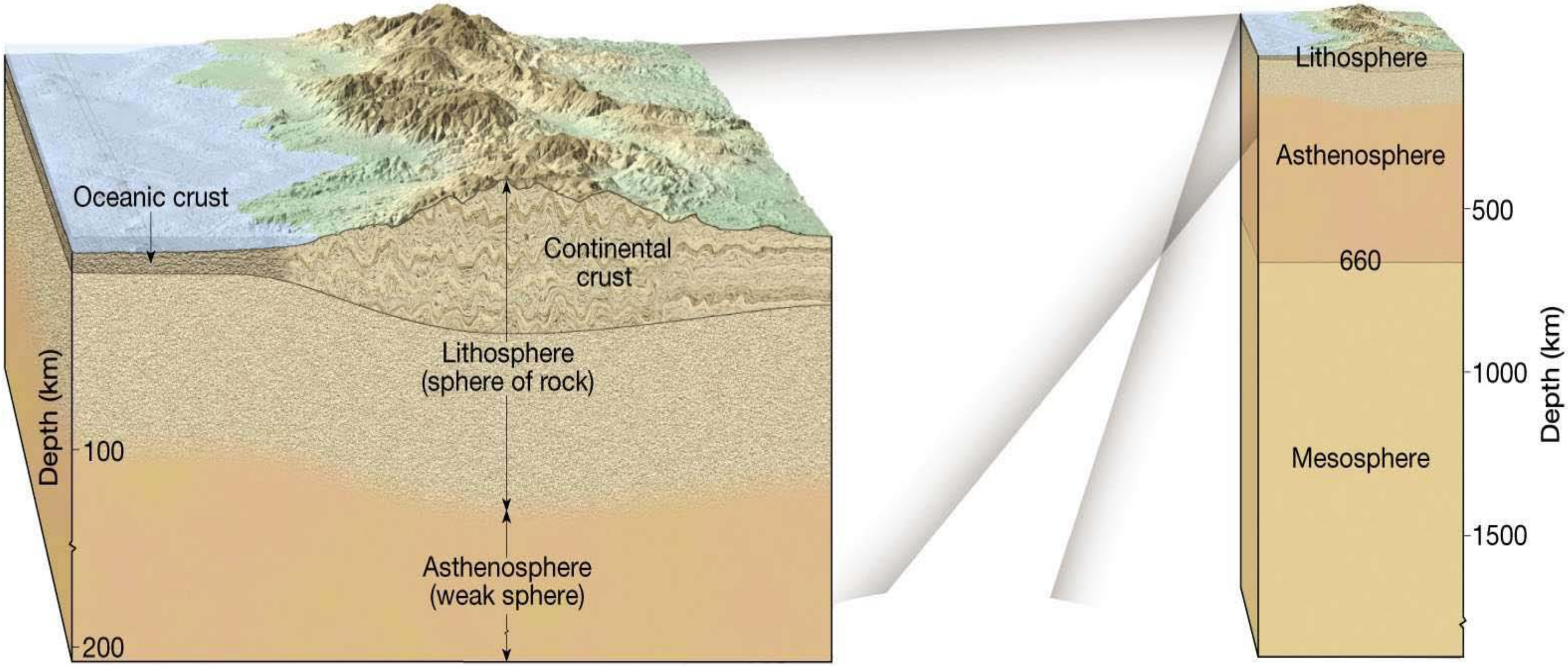
GEOLOGY 1--Physical Geology
Lecture #2, 2/9/2006

Topics:

- Lithospheric plates and their motions
- Types of plate boundaries or margins

- The present is the key to the past
- Relative Time
- Numerical Age
- Age of the Earth

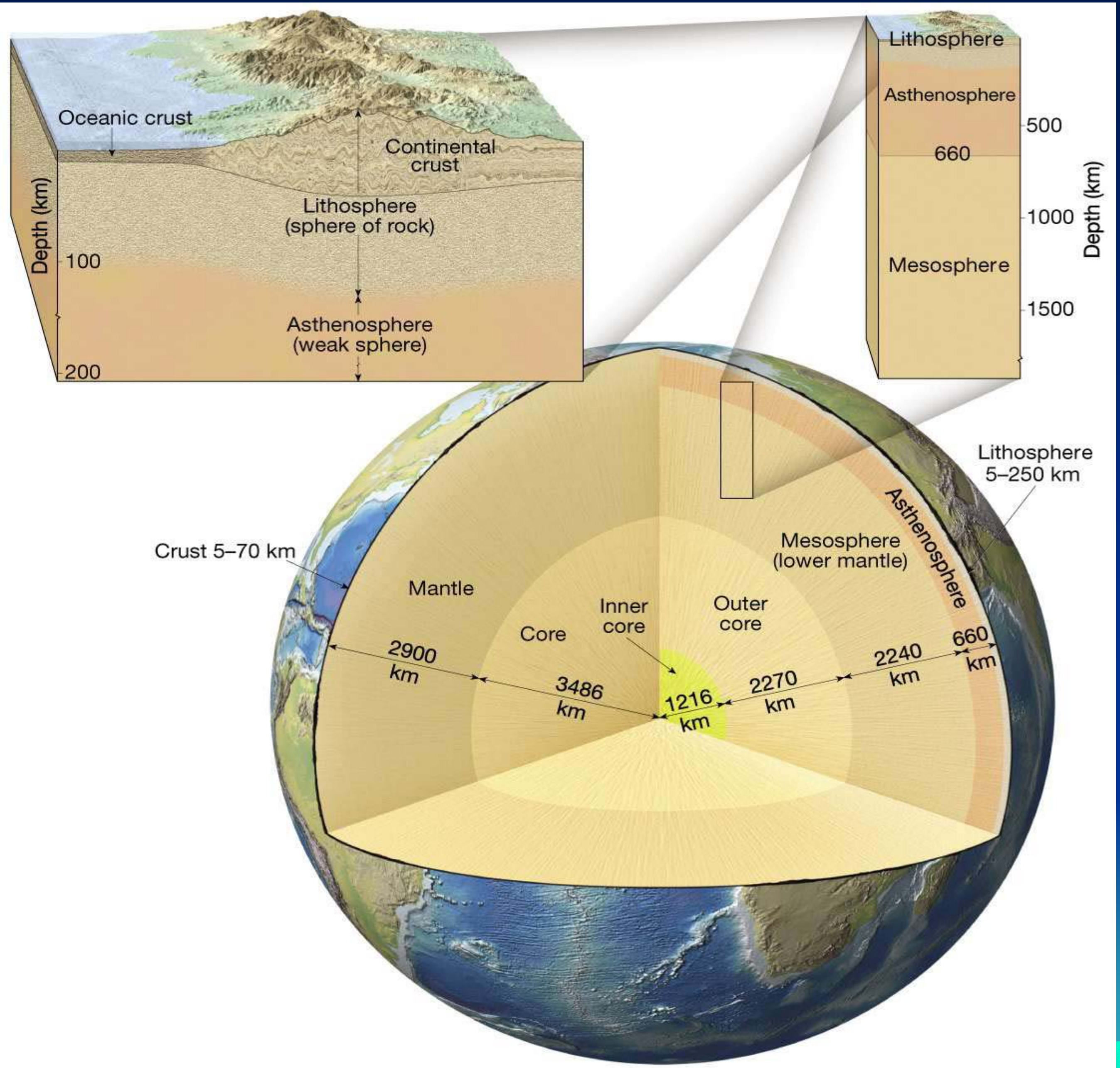


Three mechanical layers of the crust and mantle:

- ***Lithosphere*** **(crust and uppermost mantle) is strong, brittle, rigid.**
- ***Asthenosphere*** **(mantle) is plastic and deformable – it contains a small amount of molten rock or magma.**
- ***Mesosphere*** **is strong, but not brittle**

Lithosphere:

Uppermost mantle and crust

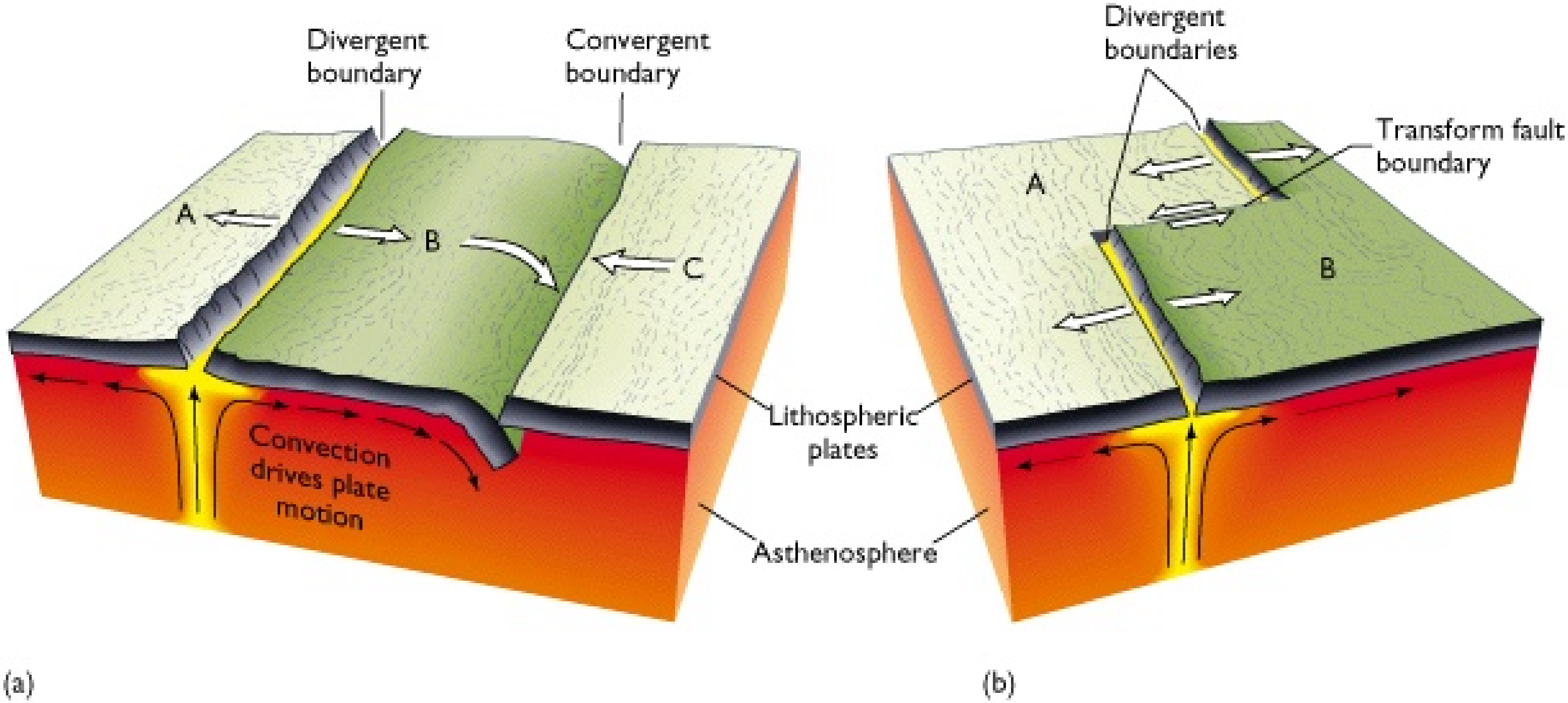


Theory of Plate Tectonics

Plate tectonics regards the **lithosphere** as broken into **plates** that are in **motion**.

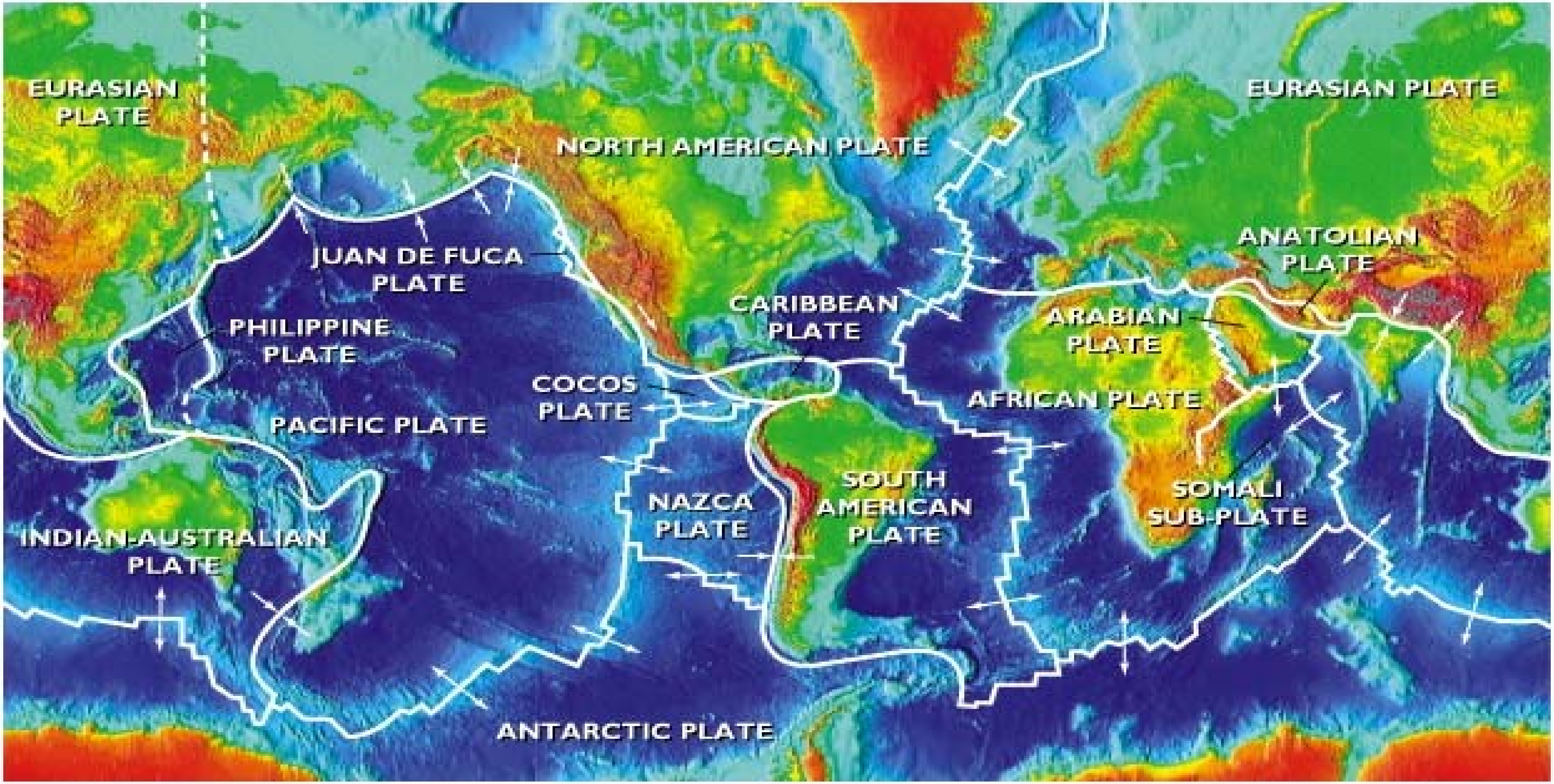
The plates **move** relative to each other, sliding on the underlying asthenosphere. The plates are much like the segments of the cracked shell on a boiled egg.

Three Kinds of plate boundaries

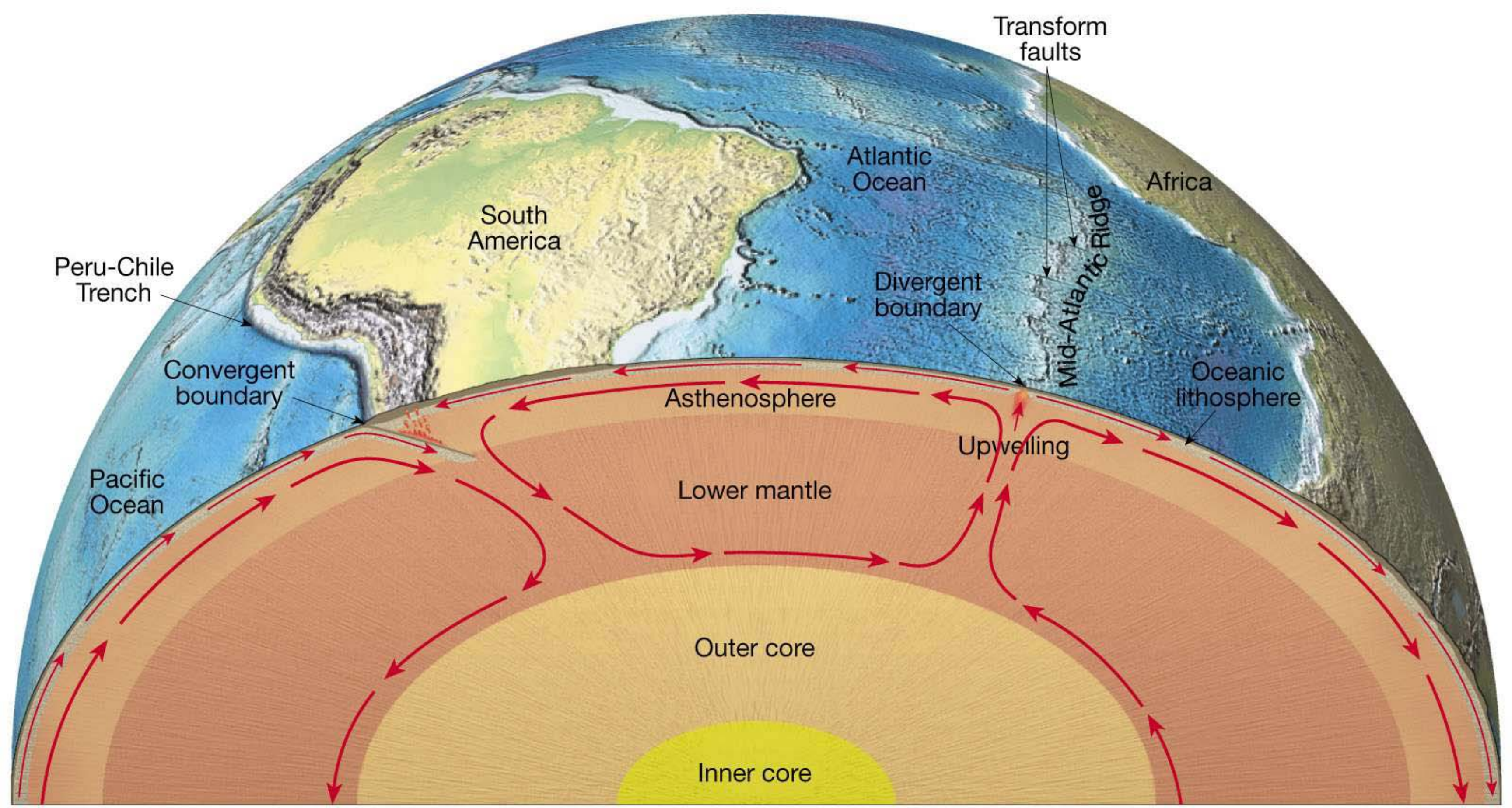


1. Divergent boundary – plates move away from each other
2. Convergent boundary – plates move toward one another, and one plate sinks or is subducted beneath the other
3. Transform boundary – plates move past one another

The lithosphere is broken into plates called lithospheric or tectonic plates

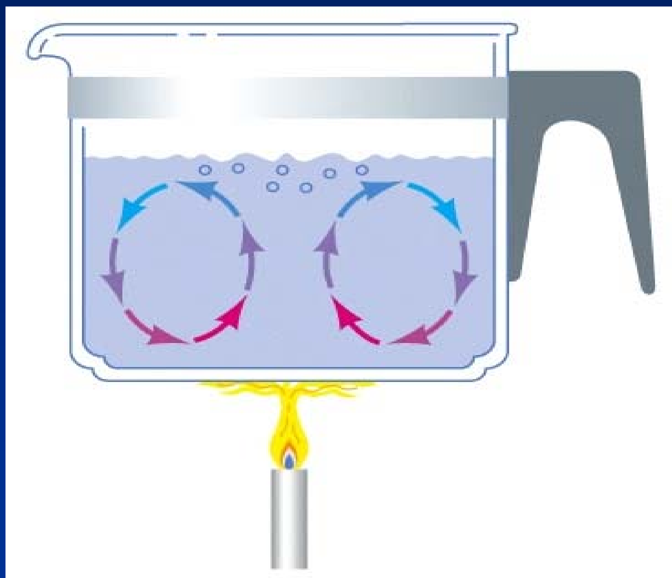


- Plates contain both oceanic and continental lithosphere
- Plates move over the asthenosphere
- Boundaries of plates are sites of convergence, divergence, shearing

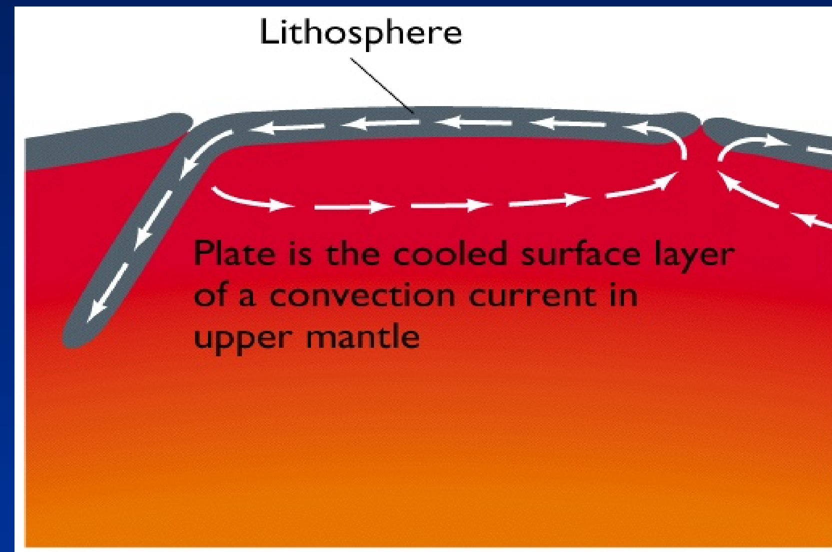


This shows the simplest possible convection pattern, with rising beneath ridges and sinking in subduction zones.

Why do plates move?
The earth cools by mantle convection.



(a)



(b)

The motions of lithospheric plates are driven by **convection** – the Earth's interior (once molten) is cooling

Chapter 8 Time and Geology

The present is the key to the past

James Hutton, father of geology, realized that geologic features in the past could be explained through present-day processes.

He realized that our mountains are not permanent but have been carved into their present shapes and will be worn down by the slow agents of erosion now working on them. The great thickness of sedimentary rocks on the continents are products of sediments removed from land and deposited in oceans. "We found no sign of beginning and no prospect for an end". He wrote in 1788. The time required for these processes to take place had to be incredibly long.

The present is the key to the past

Hutton's concept of geological processes requiring vast amount of time also influenced Charles Darwin and led the development of theory of evolution that revolutionized biology.

Charles Lyell, *Principles of Geology*, referred to Hutton's concept that geological processes operating at present are the same processes that operated in the past as the principle of uniformitarianism.

Actualism: the same processes and natural laws that operated in the past are those we can actually observe or infer from observation as operating at present. Physical laws are independent of time and location. Actualism=~ uniformitarianism

Relative time

1. Principles used to determine relative age
   1) Original Horizontality
   2) Superposition
   3) Lateral Continuity
   4) Cross-cutting Relationship
   5) Inclusion
2. Unconformities (contact that represent a GAP in geological records)
   1) Disconformity
   2) Angular unconformity
   3) Nonconformity
3. Correlation (time equivalency of rock units)
   1) Physical continuity
   2) Similarity of rock types
   3) Correlation by fossils

Principles used to determine relative age

The principle of ***original horizontality*** states that beds of sediments deposited in water formed as horizontal or nearly horizontal layers.

The principle of ***superposition*** states that within a sequence of undisturbed sedimentary or volcanic rocks, the layers get younger from bottom to top.

Principles used to determine relative age

The principle of **lateral continuity** states that an original sedimentary layer extends laterally until it tapers or thins at its edges.

The principle of **cross-cutting relationships** states that a disrupted pattern is older than the cause of disruption. A layer cake (the pattern) has to be baked (established) before it can be sliced (the disruption)

The principle of **inclusion** states that fragments included in a host rock are older than the host rock

Unconformities

(contact that represent a GAP in geological records)

1) Disconformity

2) Angular unconformity

3) Nonconformity

Unconformities

(contact that represent a GAP in geological records)

1) Disconformity
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1) Disconformity

Contact representing missing rock strata separates beds that are parallel to each other.

Implication:

- The older rocks were eroded away parallel to the bedding plane
- Renewed deposition later buried the erosion surface.

2) Angular unconformity

Younger strata overlie an erosion surface on tilted of folded layered rock.

Implications:

- Deposition and lithification of sedimentary rocks
- Uplift accompanied by folding or tilting of the layers
- Erosion
- Subsidence
- Renewed deposition

3) Nonconformity

A nonconformity is a contact in which an erosion surface on plutonic or metamorphic rock has been covered by younger sedimentary or volcanic rock.

Implications:

- Crystallization of plutonic or metamorphic rocks at depth
- Strong erosion of several >kms of overlying rocks (the great amount of erosion further implies considerable uplift of this portion of the crust)
- Deposition of new sediment

Unconformities

(a GAP in geological records)

	Disconformity	Angular unconformity	Nonconformity
Erosion	slight	moderate	strong
Lower strata	sedimentary	sedimentary	igneous
Geometry	parallel	not parallel	not parallel
Folding	no	yes	yes

Correlation (determining time equivalency of rock units)

1. Physical continuity
2. Similarity of rock types
3. Correlation by fossils

   Fossils are common in sedimentary rocks and their presence is important for correlation.

Different sedimentary layers are characterized by distinctive fossil species and that fossil species succeed one another through the layers in a predictable order. William Smith's principle of faunal succession allows rock layers in different places to be correlated based on their fossils.

Index fossils: 1) very short-lived, 2) geographically widespread, 3) known existed in a specific period of time.

Correlation by fossils

Fossils are common in sedimentary rocks and their presence is important for correlation.

Principle of Faunal Succession: different sedimentary layers are characterized by distinctive fossil species and that fossil species succeed one another through the layers in a predictable order. William Smith's principle of faunal succession allowed rock layers in different places to be correlated based on their fossils.

Index fossils: 1) very short-lived, 2) geographically widespread, 3) known existed in a specific period of time, e.g., Trilobite.

The Age of the Earth

OLD IDEAS:

1. In 1625, Archbishop James Usser: 4004 B.C. (Western Countries), before the birth of Christ October 21, 9:00 in the morning. His age determination was made by counting back generations in the Bible.

2. Hindus regarded Earth as very old (2 billion years)

3. Earth scientists in early 1800s (Uniformitarianism): very old, >hundreds of millions of years

Other Early Attempts

Sedimentation rates - 3 my – 500 my

Halley/Joly - Ocean Salinity – 100 my

Lord Kelvin (famous English Physicist) in 1866: 20-40 Myrs, calculated from the rate of cooling.

The Age of the Earth

Isotopic Dating

Discovery of radioactivity in 1986 invalidated Lord Kelvin's claim because it provided a heat source that had not known about. The decay of radioactive elements generate heat and add to the heat already in the earth.

The discovery of radioactivity also provided means to determine how old Earth is. In 1905, the first crude isotopic dates were indicate an age of about 2 billion years.

The Age of the Earth

Isotopic Dating (continued)

In 1955, CalTech geochemist Clair Patterson determined the age of the Earth at 4.55 byrs by U-Pb isotope dating. And this age has sustained enormous tests by other scientists using different radioactive isotopes.

Radioactive Revolution around 1900

Radioactive decay - spontaneous transformation of an element to another isotope of the same element or another element.

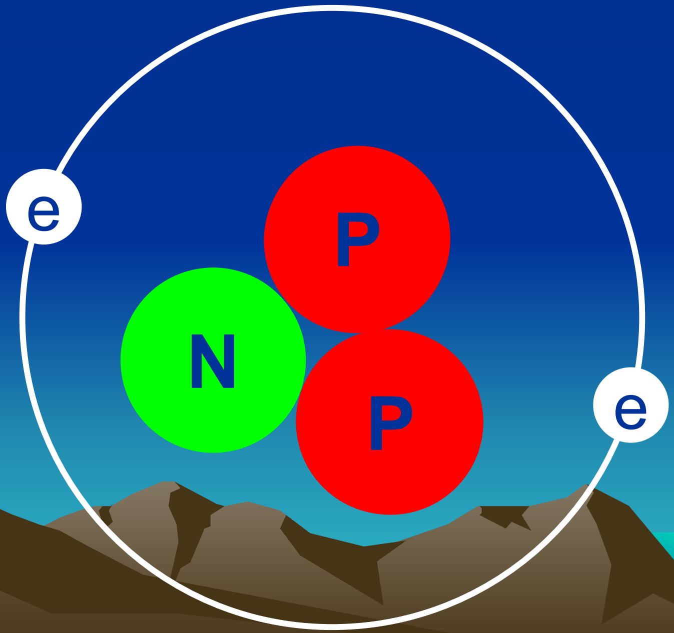
Alpha Decay – loss of a positively charged Helium ion (two protons and two neutrons)

Beta Decay – neutron splits into proton and electron

atoms

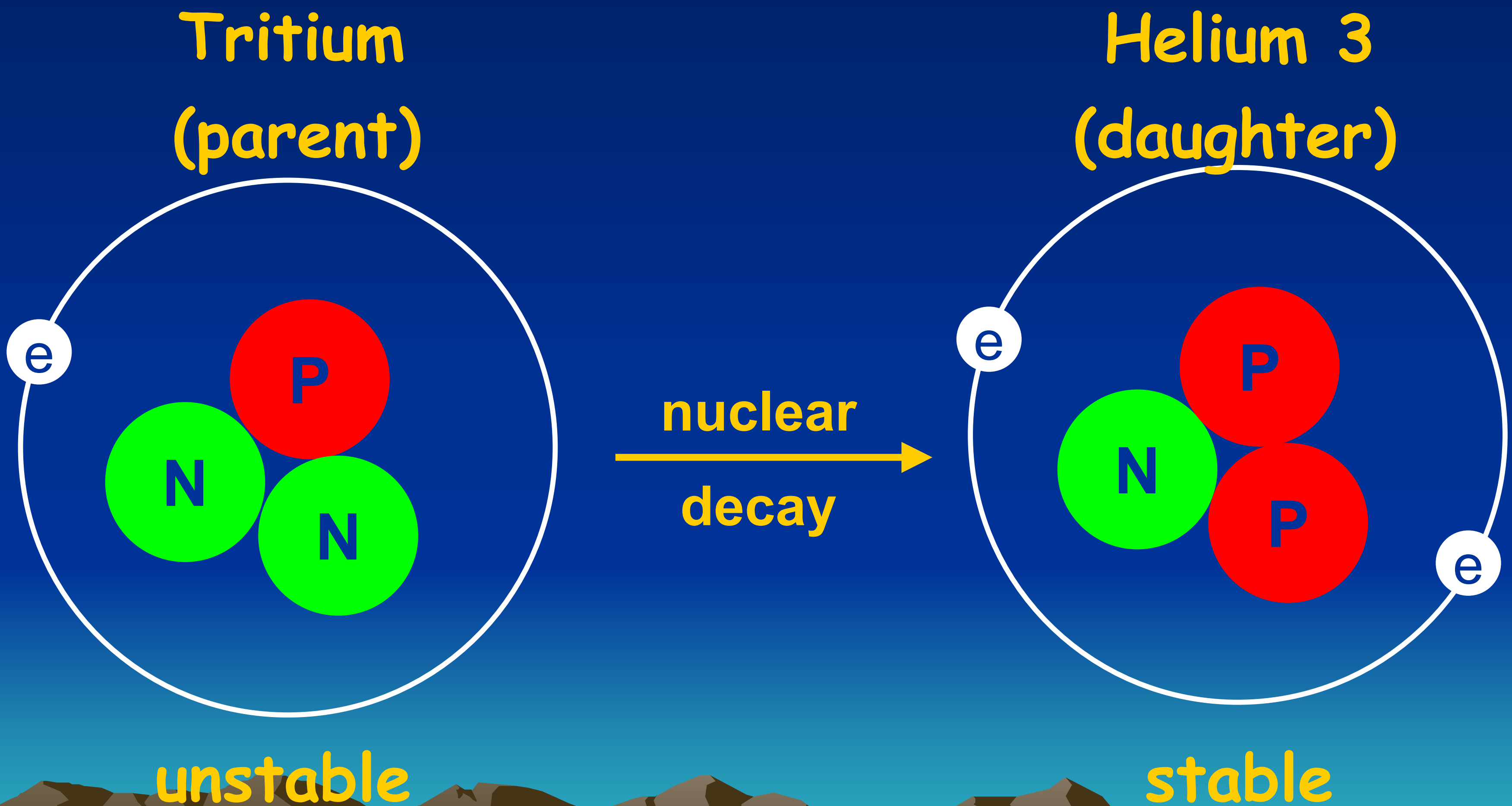
- Protons - positively charged
- Neutrons - no charge
- Electrons - negatively charged

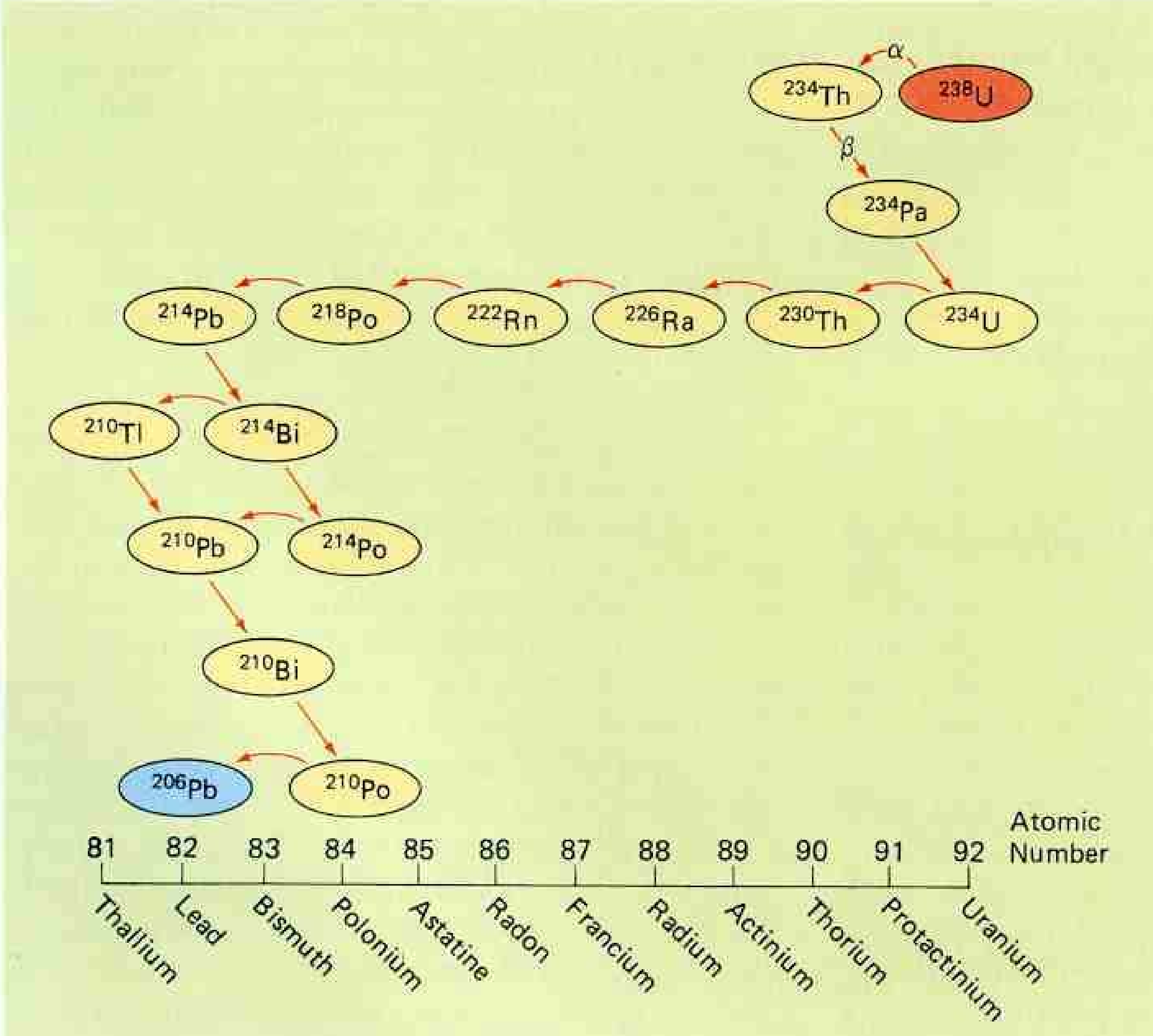
Helium 3



Radioactive Decay (Beta)

Beta Decay – neutron changes into proton and electron





α
β
234Th
238U
234Pa
214Pb
218Po
222Rn
226Ra
230Th
234U
210Tl
214Bi
210Pb
214Po
210Bi
206Pb
210Po
Atomic Number
81
82
83
84
85
86
87
88
89
90
91
92
Thallium
Lead
Bismuth
Polonium
Astatine
Radon
Francium
Radium
Actinium
Thorium
Protactinium
Uranium

Theory of radioactive dating

N is the number of radioactive atoms

$$dN/dt=-\lambda N$$

λ is the rate of decay in year^{-1}

$$N=N_0e^{-\lambda t}$$

The age of the rock is thus

$$t=(1/\lambda)\ln(N_0/N)$$

Half-life

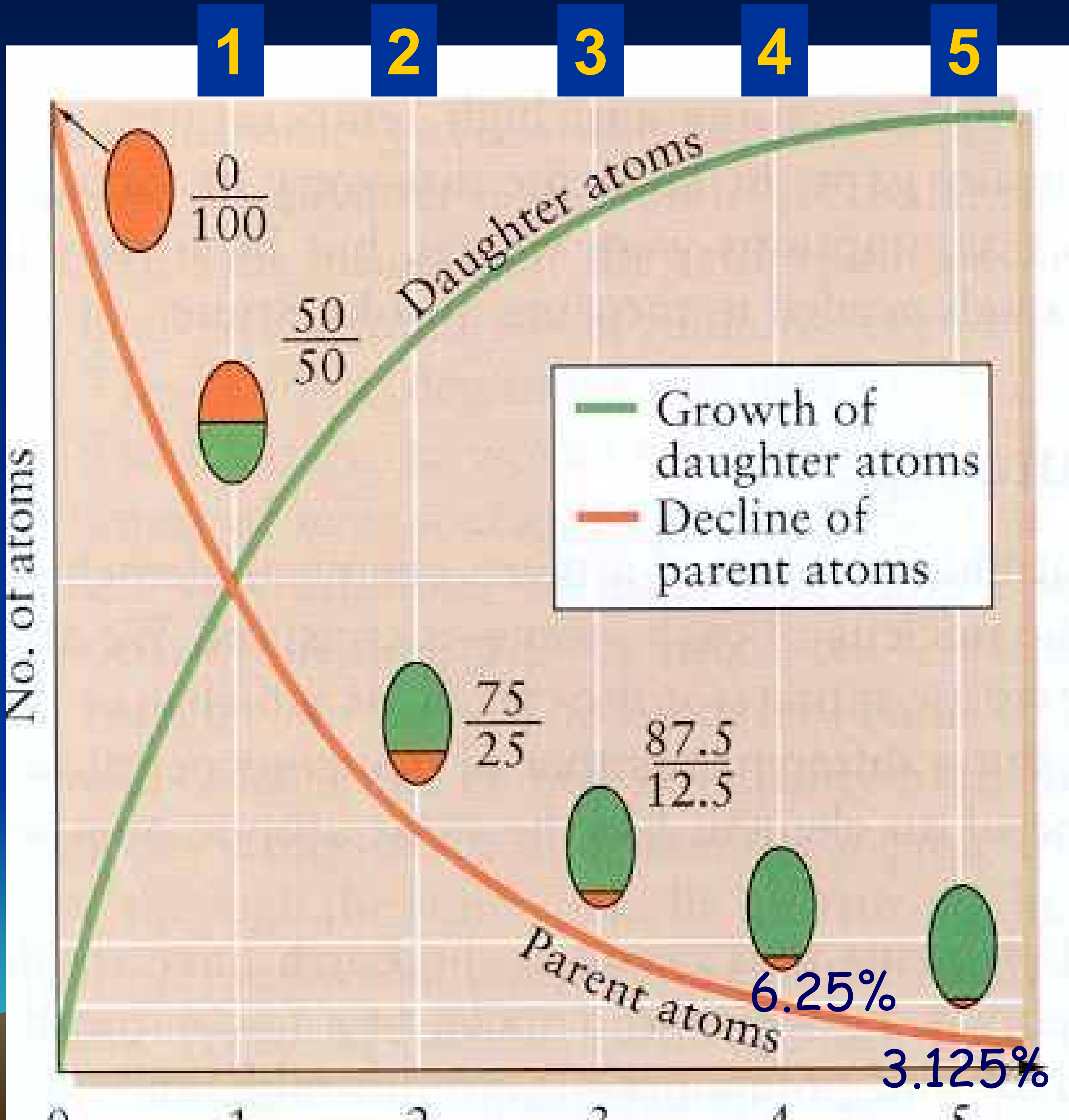
The fixed period of time during which half the parent atoms present in a closed system decay to form daughter atoms.

Half-life is related to the rate of decay (decay constant) by

$$t_{1/2}=(1/\lambda)\ln(N_0/N)= (1/\lambda)\ln 2=0.693/ \lambda$$

$$t_{1/2}=0.693/ \lambda$$

Half-Life



1
2
3
4
5
0/100
50/50
75/25
87.5/12.5
Daughter atoms
Parent atoms
Growth of daughter atoms
Decline of parent atoms
No. of atoms
6.25%
3.125%

Radiometric Dating Methods and their half lives

Cosmogenic

- C-14: 5700 Yr.
- Be-10: 2.5 M.Y.

Primordial

- K-Ar (K-40): 1.25 B.Y.
- Rb-Sr (Rb-87): 48.8 by
- U-235: 704 M.Y.
- Th-232: 14 B.Y.
- U-238: 4.5 B.Y.

Primordial

- Nd-Sm (Sm-147-Nd-143): 106 B.Y.
- Re-187 43 B.Y.
- Lu-Hf (Lu-176) 36 B.Y

Geologic Time Scale