Geologic Time

Absolute versus Relative Time

Early estimates of the age of the Earth

Basic Atomic Chemistry

Radiometric Dating

Relative Time

The Geologic Time Scale

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Absolute versus relative time

Absolute time: time in specific units (hours, days, years, etc.)

E.g., if you know my birth date you will know exactly how old I am, time passed since birth.

You could estimate my absolute age on the basis of observations.

Relative time: a time relative to another time (specific units are not known).

E.g., you could estimate the relative age of three people (relative time since each was born).

An estimation based on observation.

Absolute time

The age of the Earth?

A fundamental question that has puzzled humans for thousands of years.

Archbishop Ussher (1654): estimated the age of the Earth based on the biblical record.

Earth formed in 4004 BC, on Sunday, October 23, at 9:00 AM.

Assumed that the Earth was formed as we see it today.

(Note: it is reported that this date and time were estimated 10 years before Ussher by Dr. John Lightfoot although he is rarely cited as the originator.)

Counter-evidence (fossils folded into rock, etc.) that suggested that the Earth was older.

James Hutton (late 18th century)

Principle of Uniformitatianism

"The present is the key to the past"

Argued that today Earth features are forming slowly and constantly.

The Earth changes very slowly over time in response to natural processes that we can see acting today as they have always acted on Earth.

E.g., river valleys are cut slowly by the streams that occupy them.

These processes must have acted at the same speed and in the same manner in the past.

To form the landscape that we see today would take millions of years, much longer that the bible predicted.

Therefore, the Earth is older than 5,500 years.

Joly (1899) applied Hutton's principle to estimate the age of the Earth.

Assumed that salinity of modern oceans reflected accumulation of salts at a constant rate since the oceans formed.

Assumed that the Earth and oceans were about the same age.

Estimated the rate at which salts were delivered to the oceans by rivers.

$$\text{Age of the Earth} = \frac{\text{Total volume of salt in the oceans}}{\text{Rate of delivery of salt to the oceans}}$$

Answer: 90 million years

Didn't take into account the fact that salts precipitate out of solution.

Therefore total salts delivered to oceans is much greater than the modern salinity would suggest.

Lord Kelvin estimated the age of the Earth based on rates of cooling.

Assumed that the Earth was initially molten.

Assumed that Earth cooled at a constant rate and estimated that rate.

$$\text{Age of the Earth} = \frac{\text{Initial temperature} - \text{current temperature}}{\text{Estimated rate of cooling}}$$

Answer: 20-40 million years.

Kelvin didn't know that heat is also constantly added to the Earth by radioactive decay of elements within the Earth.

Therefore, his estimate was much less than the actual age.

Another estimate was based on the total thickness of sedimentary rocks.

Total thickness = about 150,000 metres.

Average modern sedimentation rate = 0.3 m/1000 years

$$\text{Age of the Earth} = \frac{\text{150,000 metres of rock}}{\text{Sedimentation at 0.0003m/yr}}$$

Answer: 500,000,000 years.

Underestimating the true age:

Not all sedimentary strata that have been deposited are preserved; much has been eroded, currently and in the past.

The modern sedimention rate is higher than the long term average.

Application of the Principle of Uniformitarianism has its flaws.

The same processes may have acted in the past, maybe not at the same rate as at the present time.

Radiometric Dating

A method for estimating the absolute age of rocks.

Basic atomic chemistry

Element: the simplest kind of chemical; it cannot be broken down into simpler forms by any physical or chemical process.

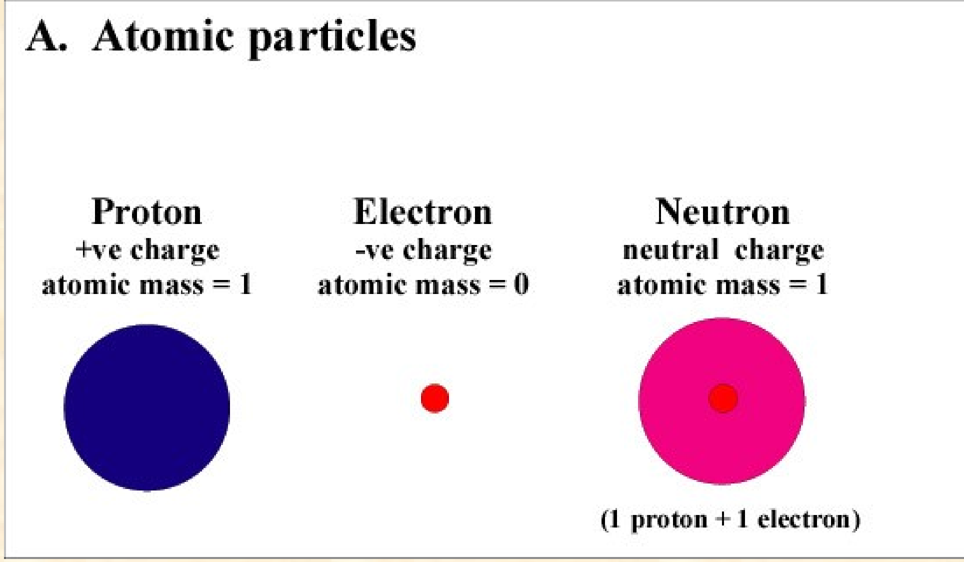
Atoms: the smallest particle of an element that retains the characteristics of elements.

Atoms are made up of:

Protons (+ve charge, mass = 1)

Electrons (–ve charge, mass = 0)

Neutrons (1 proton + 1electron, mass=1)



Atoms are made up of:

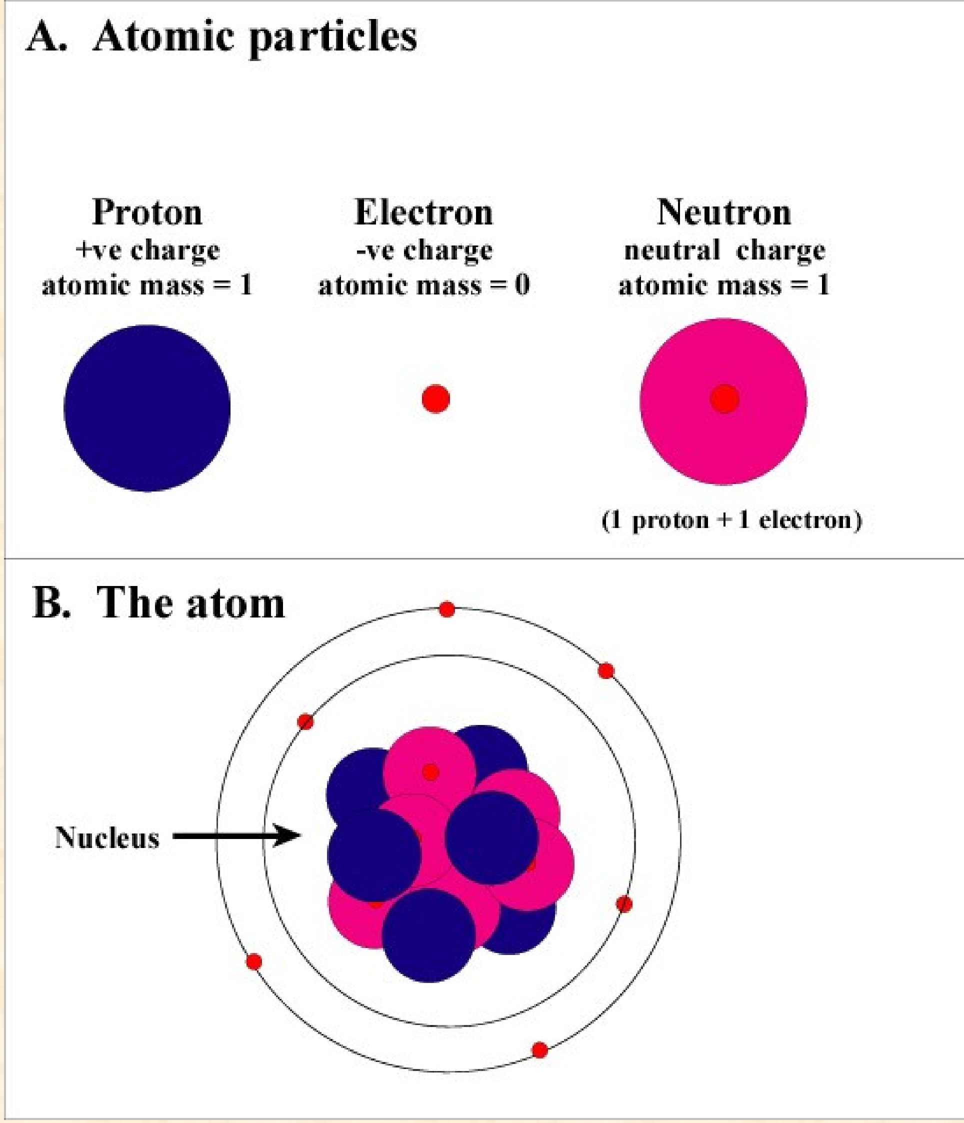
Protons (+ve charge, mass = 1)

Electrons (–ve charge, mass = 0)

Neutrons (1 proton + 1electron, mass=1)

Nucleus of an atom: a combination of neutrons and protons.

Electrons orbit the nucleus, forming an electron cloud.



# of electrons = # of protons   # of protons may not = # of neutrons

Atomic Number: total number of protons in the nucleus of the atoms of an element.

Defines the element; if atomic number changes then the element changes.

Atomic mass: total mass of all protons and neutrons (electrons have negligible mass)

Periodic Table: the list of all known elements in order of increasing atomic number.

Notation:

e.g.

$^{8}O^{16}$

O = oxygen

8 = atomic number (8 protons)

16=atomic mass (8 protons + 8 neutrons = 16)

Periodic Table of the Elements

Key: ^{37}Rb^{85} Rubidium (87) — Atomic number; Symbol of element; Atomic weight; Name of element; Isotope used for radiometric dating

Solid — Liquid — Inert gas — Gas — Elements with isotopes used for radiometric dating

Light Metals (I A, II A) — **Transitional Elements** / **Heavy Metals** (III B – II B) — **Nonmetals** (III A – VII A)

	I A	II A	III B	IV B	V B	VI B	VII B	VIII B	VIII B	VIII B	I B	II B	III A	IV A	V A	VI A	VII A	VIII A
1	^{1}H^{1} Hydrogen																	^{2}He^{4} Helium
2	^{3}Li$^{7}_{7}$ Lithium	^{4}Be$^{9}_{9}$ Beryllium											^{5}B^{11} Boron	^{6}C^{12} Carbon (14)	^{7}N^{14} Nitrogen	^{8}O^{16} Oxygen	^{9}F^{19} Flourine	^{10}Ne^{20} Neon
3	^{11}Na^{23} Sodium	^{12}Mg^{24} Magnesium											^{13}Al^{27} Aluminum	^{14}Si^{28} Silicon	^{15}P^{31} Phosphorus	^{16}S^{32} Sulfur	^{17}Cl^{35} Chlorine	^{18}Ar^{40} Argon
4	^{19}K^{39} Potassium (40)	^{20}Ca^{40} Calcium	^{21}Sc^{45} Scandium	^{22}Ti^{48} Titanium	^{23}V^{51} Vanadium	^{24}Cr^{52} Chromium	^{25}Mn^{55} Manganese	^{26}Fe^{56} Iron	^{27}Co^{59} Cobalt	^{28}Ni^{59} Nickel	^{29}Cu^{63} Copper	^{30}Zn^{65} Zinc	^{31}Ga^{70} Gallium	^{32}Ge^{73} Germanium	^{33}As^{75} Arsenic	^{34}Se^{79} Selenium	^{35}Br^{80} Bromine	^{36}Kr^{84} Krypton
5	^{37}Rb^{85} Rubidium (87)	^{38}Sr^{88} Strontium	^{39}Y^{89} Yttrium	^{40}Zr^{91} Zirconium	^{41}Nb^{93} Niobium	^{42}Mo^{96} Molybdenum	^{43}Tc^{99} Technetium	^{44}Ru^{101} Ruthenium	^{45}Rh^{103} Rhodium	^{46}Pd^{106} Palladium	^{47}Ag^{108} Silver	^{48}Cd^{112} Cadmium	^{49}In^{115} Indium	^{50}Sn^{119} Tin	^{51}Sb^{122} Antimony	^{52}Te^{128} Tellurium	^{53}I^{127} Iodine	^{54}Xe^{131} Xenon
6	^{55}Cs^{133} Cesium	^{56}Ba^{137} Barium	See 57-71	^{72}Hf^{178} Hafnium	^{73}Ta^{181} Tantalum	^{74}W^{184} Tungsten	^{75}Re^{186} Rhenium	^{76}Os^{190} Osmium	^{77}Ir^{192} Iridium	^{78}Pt^{195} Platinum	^{79}Au^{197} Gold	^{80}Hg^{201} Mercury	^{81}Tl^{204} Thallium	^{82}Pb^{208} Lead	^{83}Bi^{209} Bismuth	^{84}Po^{210} Polonium	^{85}At^{210} Astatine	^{86}Rn^{222} Radon
7	^{87}Fr^{223} Francium	^{88}Ra^{226} Radium	See 89-103															

Lanthanide series	^{57}La^{139} Lanthanum	^{58}Ce^{140} Cerium	^{59}Pr^{141} Praseodymium	^{60}Nd^{144} Neodymium	^{61}Pm^{147} Promethium	^{62}Sm^{150} Samarium (147)	^{63}Eu^{152} Europium	^{64}Gd^{157} Gadolinium	^{65}Tb^{159} Terbium	^{66}Dy^{163} Dysprosium	^{67}Ho^{165} Holmium	^{68}Er^{167} Erbium	^{69}Tm^{169} Thullium	^{70}Yb^{173} Ytterbium	^{71}Lu^{175} Lutetium
Actinide series	^{89}Ac^{227} Actinium	^{90}Th^{232} Thorium (232)	^{91}Pa^{231} Protactinium	^{92}U^{238} Uranium (235, 238)	^{93}Np^{237} Neptunium	^{94}Pu^{242} Plutonium	^{95}Am^{243} Americium	^{96}Cm^{247} Curium	^{97}Bk^{249} Berkelium	^{98}Cf^{251} Californium	^{99}Es^{254} Einsteinium	^{100}Fm^{256} Fermium	^{101}Md^{256} Mendelevium	^{102}No^{254} Nobelium	^{103}Lw^{257} Lawrencium

Note that not all elements have an equal number of protons and neutrons.

In many elements there are more neutrons than protons.

e.g. Potassium: $^{19}K^{39}$ 19 protons and 20 neutrons.

Gold: $^{79}Au^{197}$ Atomic Number = 79, Atomic Mass = 197

197 – 79 = 118 neutrons.

118 – 79 = 39 more neutrons than protons.

In general, the larger the atomic number and mass, the greater the number of excess neutrons.

More neutrons needed to hold bigger nuclei together.

Isotopes: forms of elements with different atomic mass.

For a given element the atomic number remains the same, therefore the number of neutrons is different.

Uranium has 3 common isotopes:

$^{92}U^{234}$

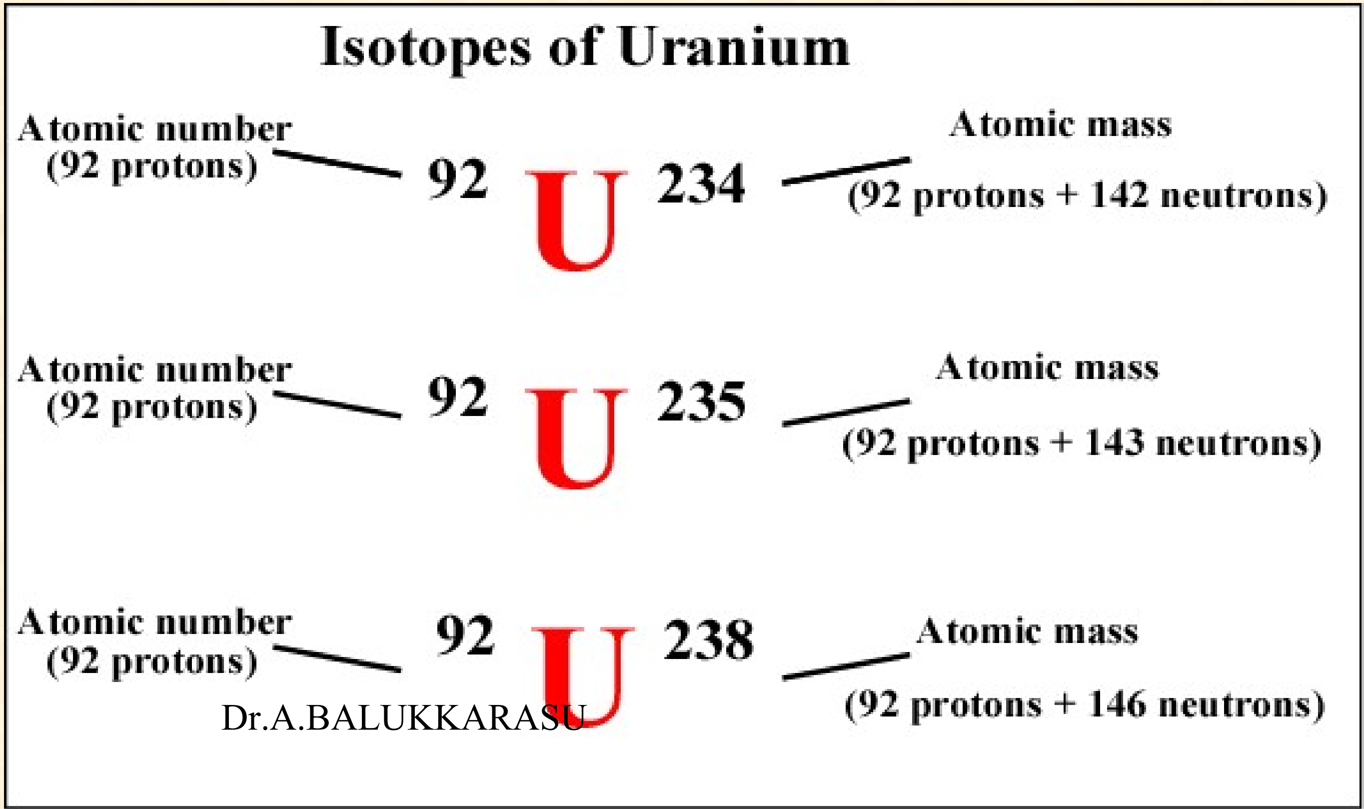
50 excess neutrons

$^{92}U^{235}$

51 excess neutrons

$^{92}U^{238}$

54 excess neutrons



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Radioactive isotopes: isotopes of elements that change spontaneously by losing or gaining subatomic particles.

Original Element
(Parent Isotope)

↓ Radioactive decay

New Element
(daughter product; radioactively stable)

Types of radioactive decay:

Alpha (α) particle emission:

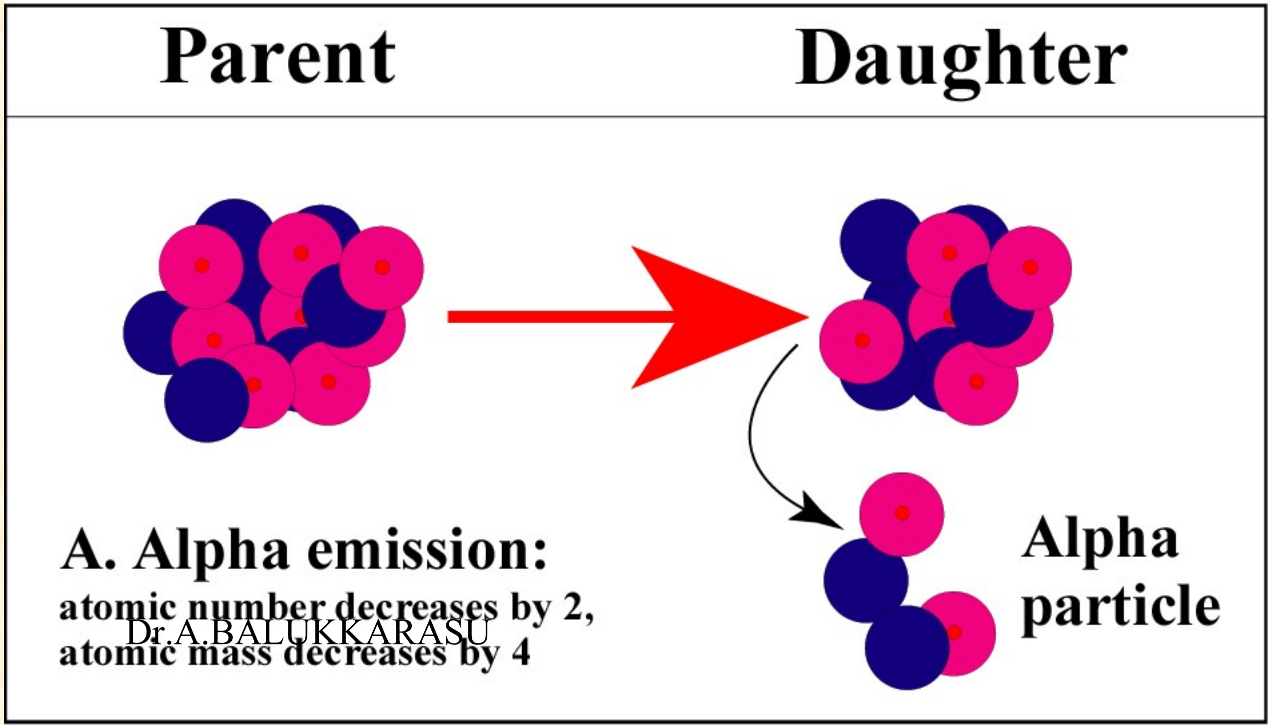
Loss of an alpha particle from a nucleus.

Alpha particle = 2 protons + 2 neutrons.

Atomic number decreases by 2. **Atomic mass decreases by 4.**

e.g,

$^{92}U^{238} - \alpha = {}^{90}Th^{234}$



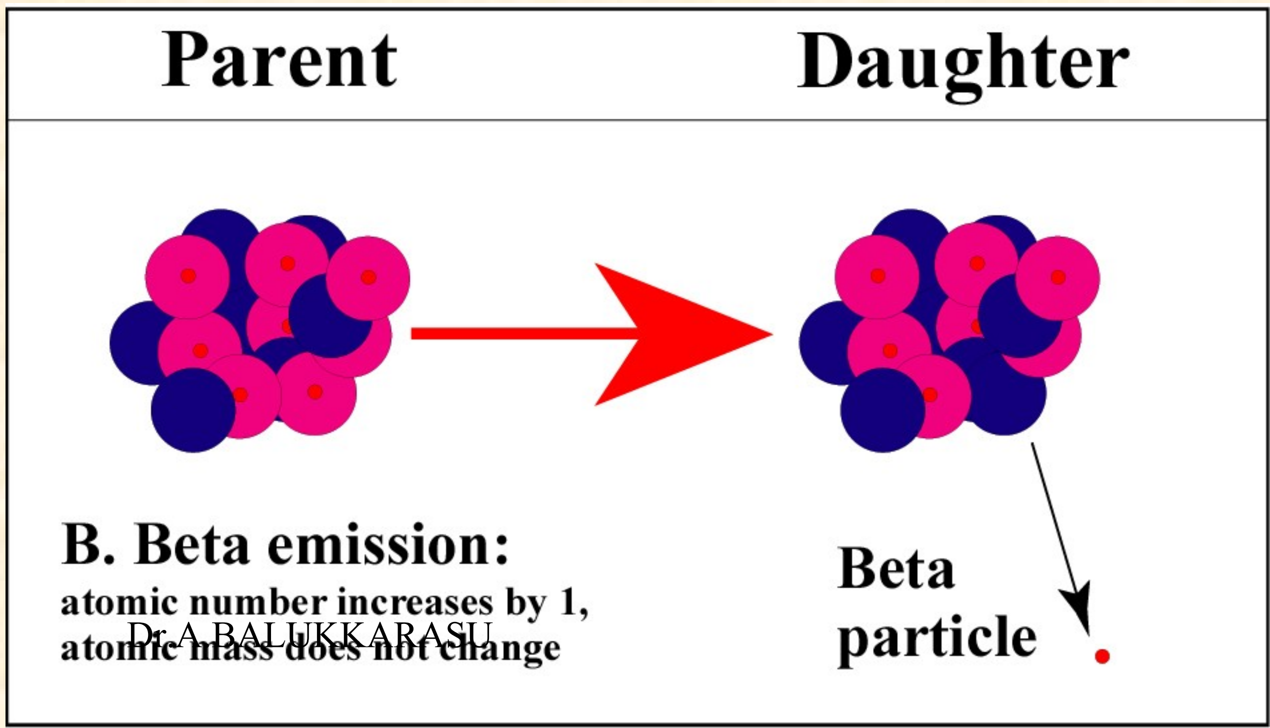
Beta (β) particle emission:

Loss of a beta particle (electron) from a neutron changing it to a proton.

Atomic number increases by 1. Atomic mass is unchanged.

e.g.,

$^{90}Th^{234} - \beta = {}^{91}Pa^{234}$



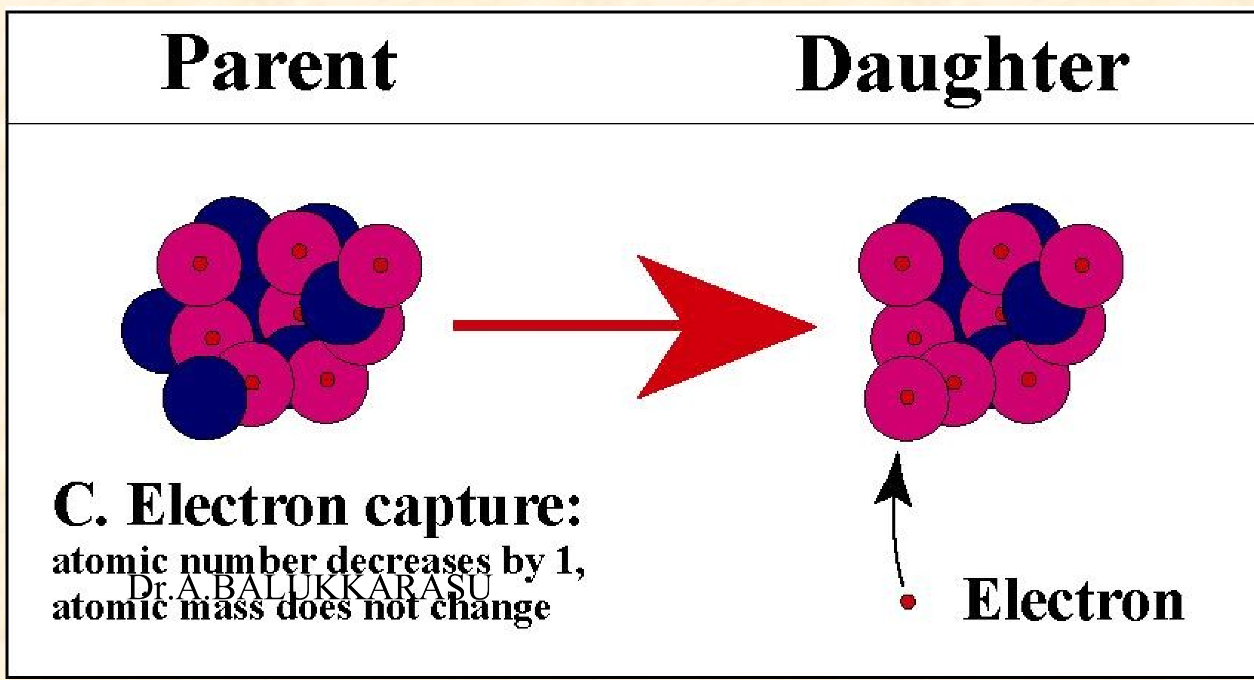
Electron Capture:

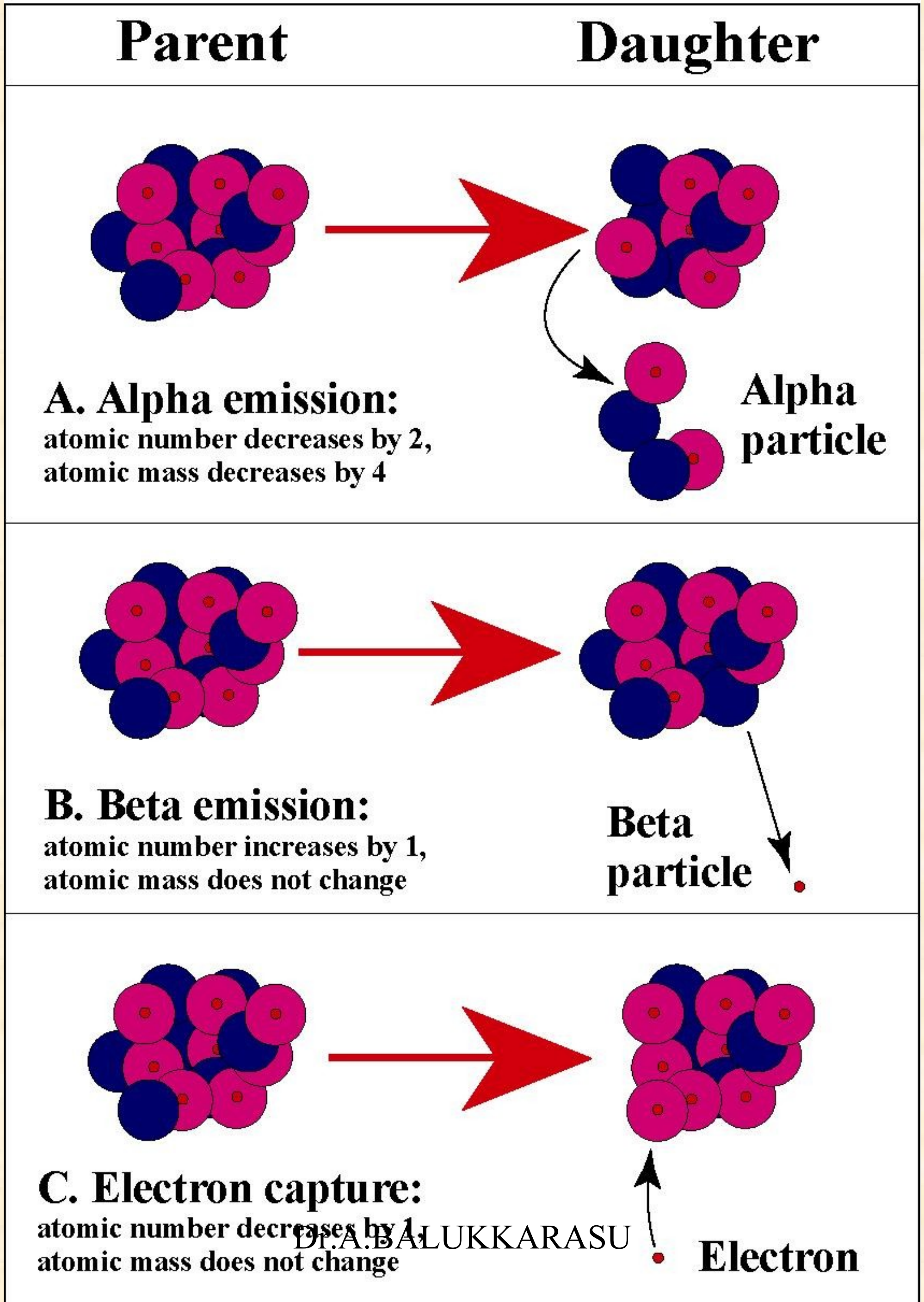
Addition of an electron to a proton, changing it to a neutron.

Atomic number decreases by 1.   Atomic mass is unchanged.

e.g.,

$^{92}U^{238} + \beta = {}^{91}Pa^{238}$




Parent
Daughter
A. Alpha emission:
atomic number decreases by 2,
atomic mass decreases by 4
Alpha
particle
B. Beta emission:
atomic number increases by 1,
atomic mass does not change
Beta
particle
C. Electron capture:
atomic number decreases by 1,
atomic mass does not change
Electron

For many isotopes the change from parent element to stable daughter product does so through many steps.

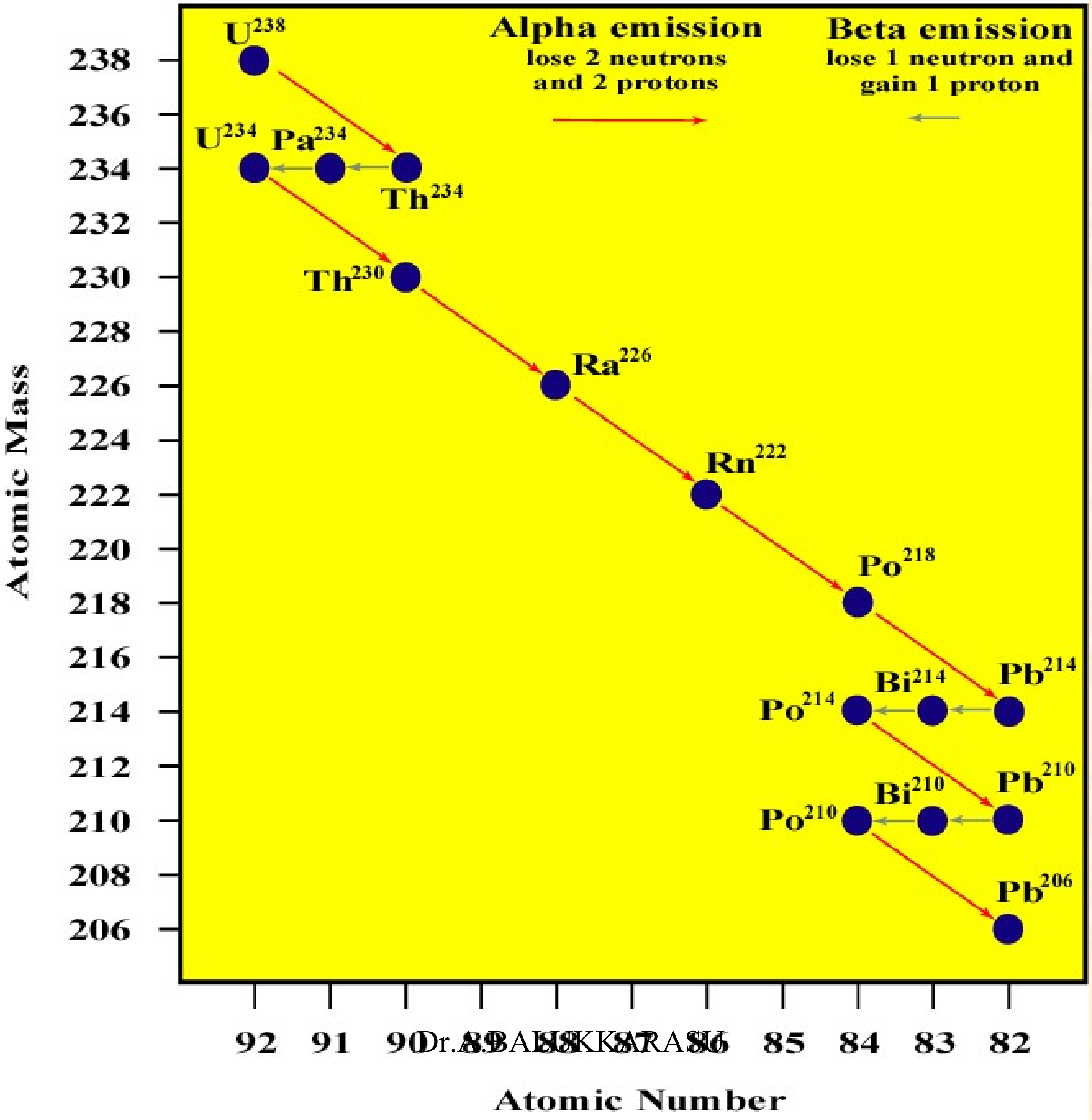
The path from parent element to stable daughter produce is termed the Radioactive Series for the parent.

Parent element **Daughter product**

$$^{92}U^{238} \xrightarrow[\text{14 steps } (\alpha \text{ and } \beta \text{ emissions})]{\text{Radioactive series}} {}^{82}Pb^{206}$$

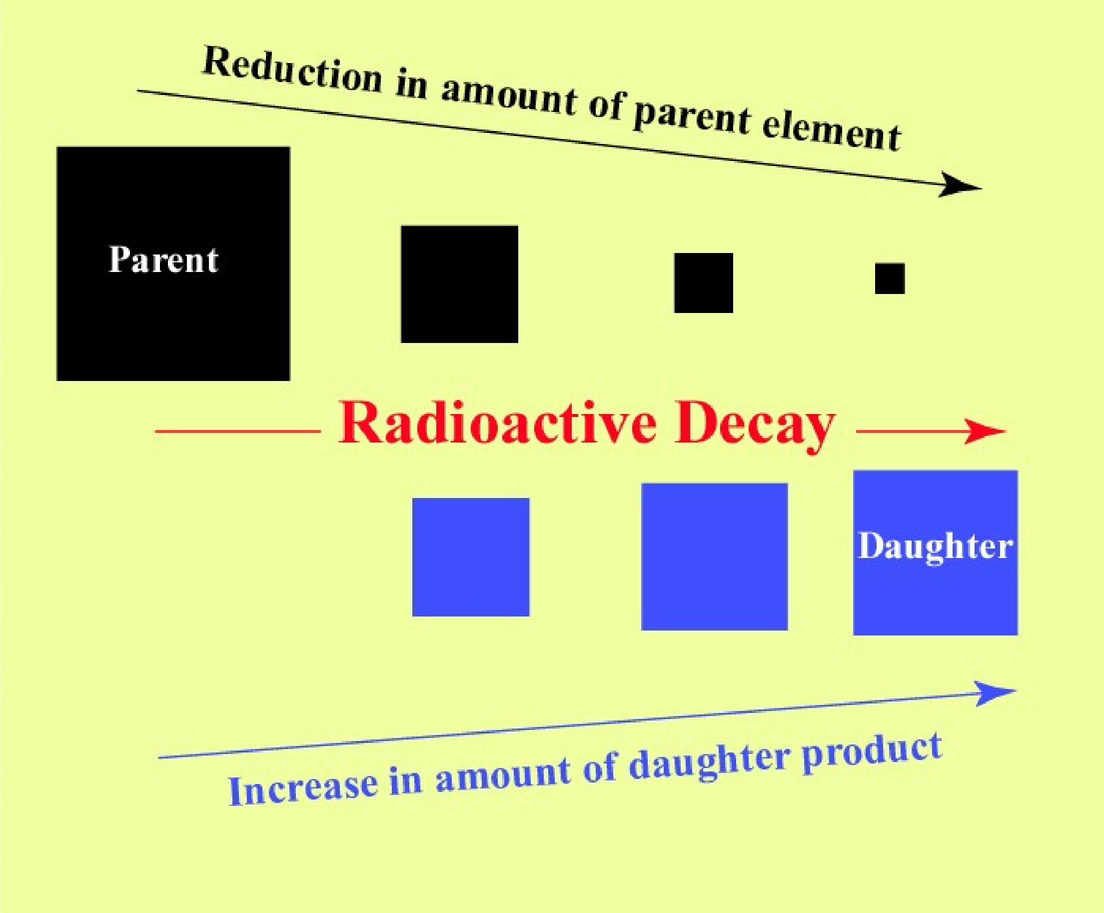
(Uranium) (Lead)

Radioactive decay series of U^{238}



Radioactive decay takes place at a constant rate and has done so over all of geologic time.

Parent is reduced in amount.



Daughter product increases in amount.

At a constant rate.

Half-life of an isotope: the time taken for the amount of parent to be reduced by ½.

Over successive half lives the parent is constantly reduced in amount and the daughter increases in amount.

The half-life of uranium^{238} is 4.5 billion years:

Starting with 1000 atoms of U^{238}, after 4.5 billion years there will be 500 atoms of U^{238} and 500 atoms of Pb^{206}.

Each of the 14 steps in the U^{238} radioactive decay series has a half-life:

U^{238}	**→**	**Th^{234}**	**4.5 billion years**
Ra^{226}	**→**	**Rn^{222}**	**1600 years**
Rn^{222}	**→**	**Po^{218}**	**3.82 days**
Po^{218}	**→**	**Pb^{214}**	**3.1 minutes**
Pb^{214}	**→**	**Bi^{214}**	**26.8 minutes**
Bi^{214}	**→**	**Po^{214}**	**19.7 minutes**
Po^{214}	**→**	**Pb^{210}**	**1.6×10^{-4} seconds**
Pb^{210}	**→**	**Bi^{210}**	**20.4 years**
Bi^{210}	**→**	**Po^{210}**	**5.0 days**
Po^{210}	**→**	**Pb^{206}**	**138 days**
Pb^{206}		**Stable daughter product.**	

Radiometric dating:

If we know the half-life of a radioactive decay series for an isotope and the initial ratio of parent to daughter then we can determine the age of any material containing that isotope.

Assuming:

1. The parent has been trapped in the material at the time the material formed (none added and none removed other than by decay).

2. The initial amount of daughter product is known and has not changed by addition or loss, except by radioactive decay.

Daughter product is commonly only produced by radioactive decay: initial amount is zero.

e.g, Potassium-40 is an isotope that is commonly used for dating rocks.

Half-life = 1.25 billion years

$^{19}K^{40}$ decays to two different isotopes: $^{18}Ar^{40}$ and $^{20}Ca^{40}$

11% of K^{40} decays to Ar^{40}

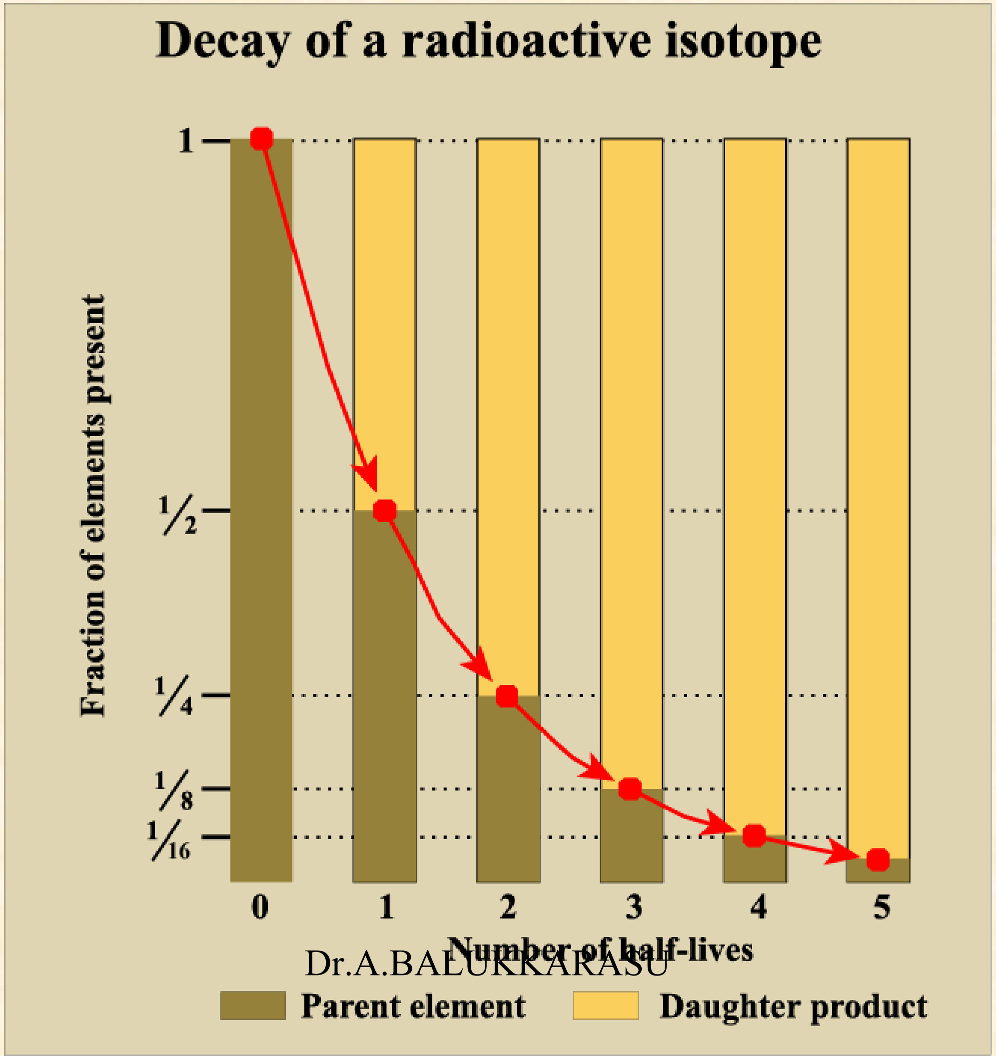
89% K^{40} decays to Ca^{40}

100% of Ar^{40} in a rock is produced by the decay of K^{40}.

Whereas Ca^{40} is also a common element in many minerals (we don't know the initial amount).

Therefore, radiometric dating by K^{40} relies on the Ar^{40} daughter product.

If we know the half-life of an isotope and we can measure the amount of daughter product that is present in a rock, we can determine the age of the rock. (Although sometimes the amount remaining of parent is used to determine the age.)



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Common isotopes used for radiometric dating of rocks have half-lives ranging from 106 billion years (samarium^{147}) to 5,730 years (carbon^{14}).

Parent Isotope	Half-life	Stable daughter product	Effective age range
Samarium^{147}	106 billion years	Neodymium^{143}	>100 million years
Rubidium^{87}	47 billion years	Strontium^{87}	>100 million years
Thorium^{232}	14.1 billion years	Lead^{208}	>200 million years
Uranium^{238}	4.5 billion years	Lead^{206}	>100 million years
Potassium^{40}	1.25 billion years	Argon^{40}	>100,000 years
Uranium^{235}	713 million years	Lead^{207}	>100 million years
Carbon^{14}	5,730 years	Nitrogen^{14}	0-60,000 years

Carbon-14 dating

Used to date fossil remains, or sediment containing fossils, with original material unchanged (no replacement).

Assumes that the age of the fossils is equal to the time since the sediment was deposited.

Common isotope of carbon:

$^{6}C^{12}$, 6 protons and 6 neutrons.

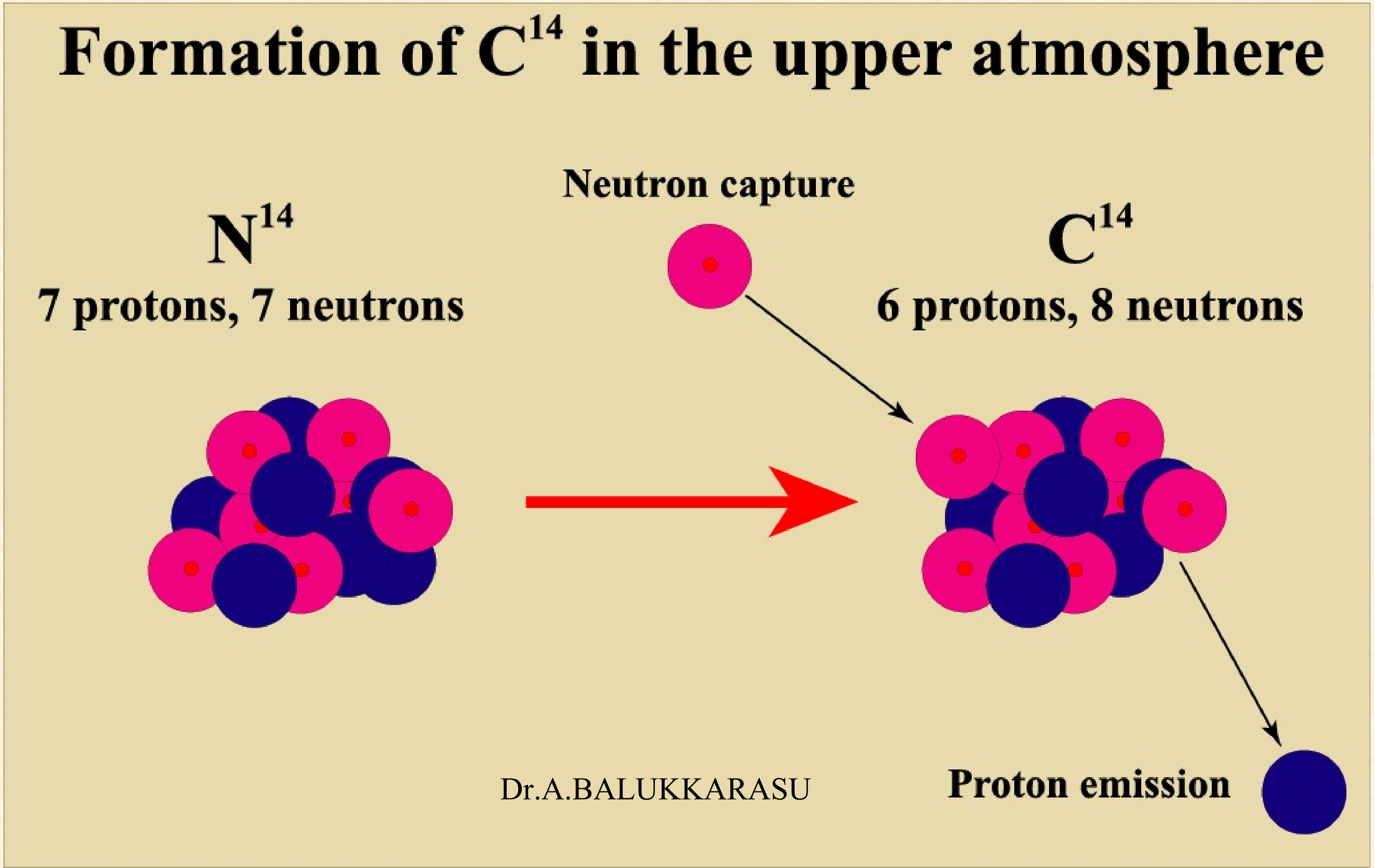
Contained in every living organism.

Carbon-14 is a radioactive isotope:

$^{6}C^{14}$, 6 protons and 8 neutrons.

C^{14} is produced in the atmosphere from nitrogen-14 (N^{14}) due to the action of *cosmic rays* (high energy particles derived from the sun).

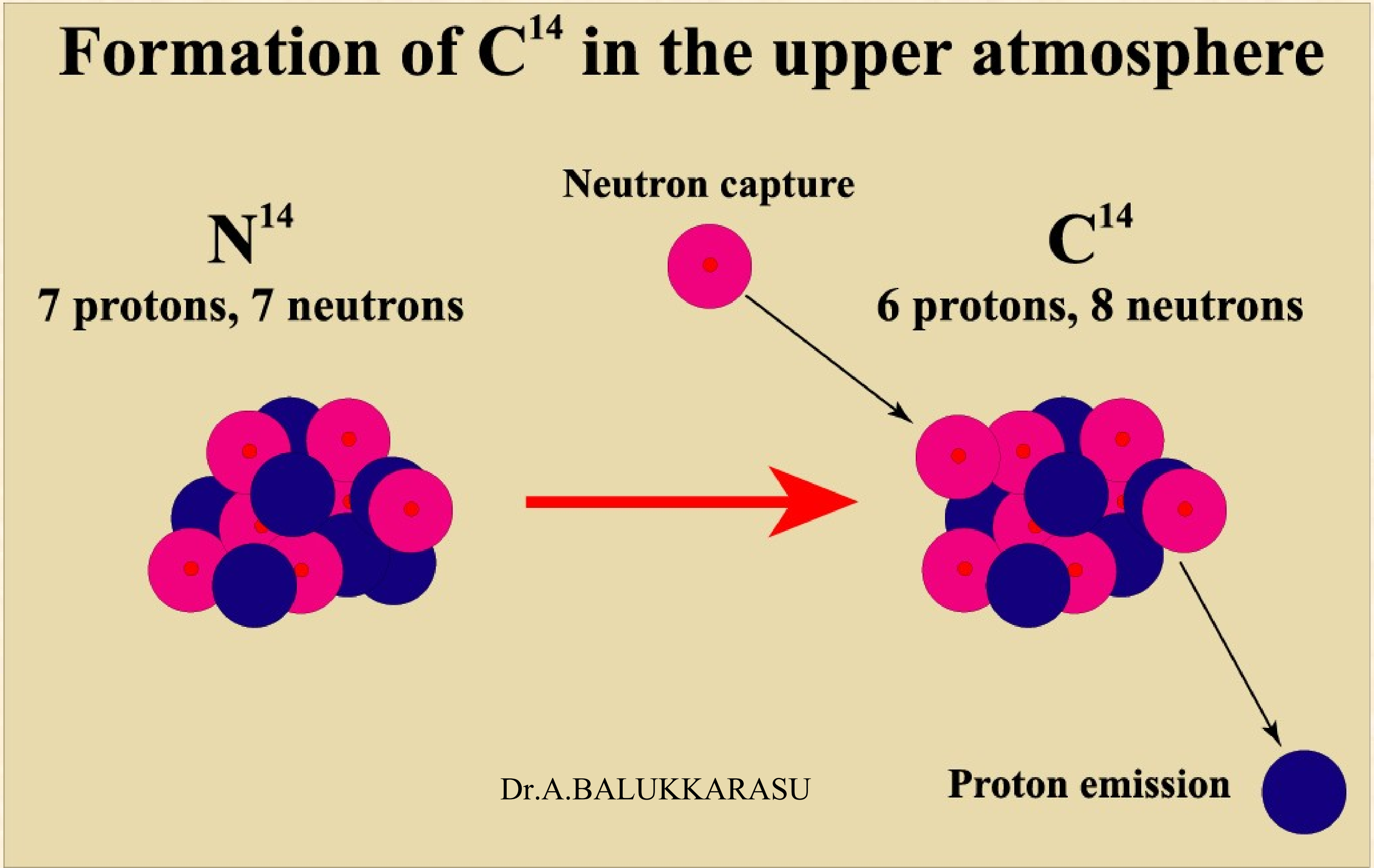
When such particles strike atoms of some gases they shatter their nuclei, releasing protons and neutrons.



When a free neutron hits an atom of nitrogen (N^{14}) it knocks a proton out and becomes part of the nucleus.

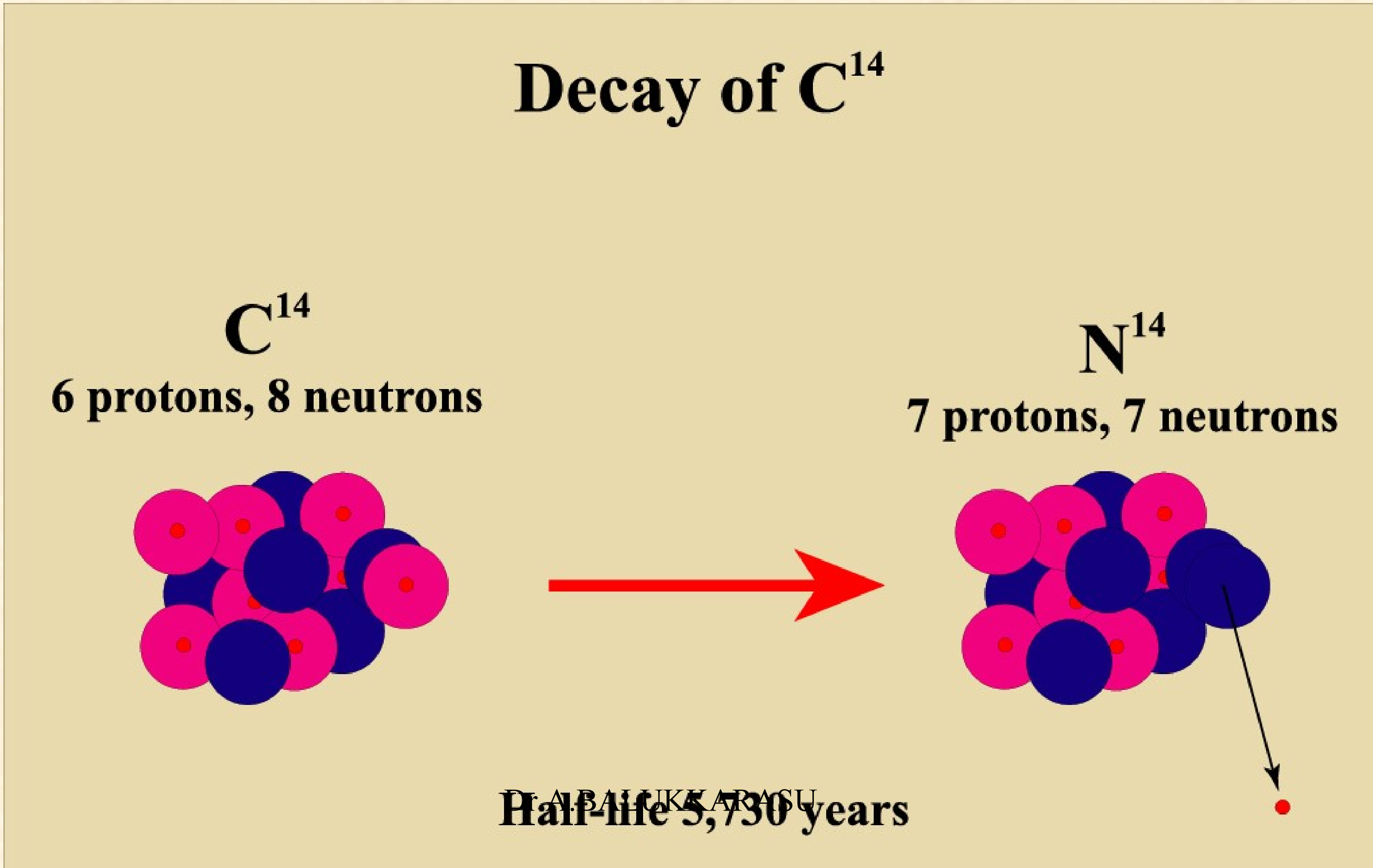
The atomic number decreases by 1 and atomic mass remains the same.

$$^{7}N^{14} - \text{proton} + \text{neutron} = {}^{6}C^{14}$$



Carbon–14 makes up about 10^{-10} % of the carbon in the atmosphere. (0.0000000001%).

C^{14} decays back to N^{14} by β-particle emission: $\;{}^{6}C^{14} - \beta = {}^{7}N^{14}$



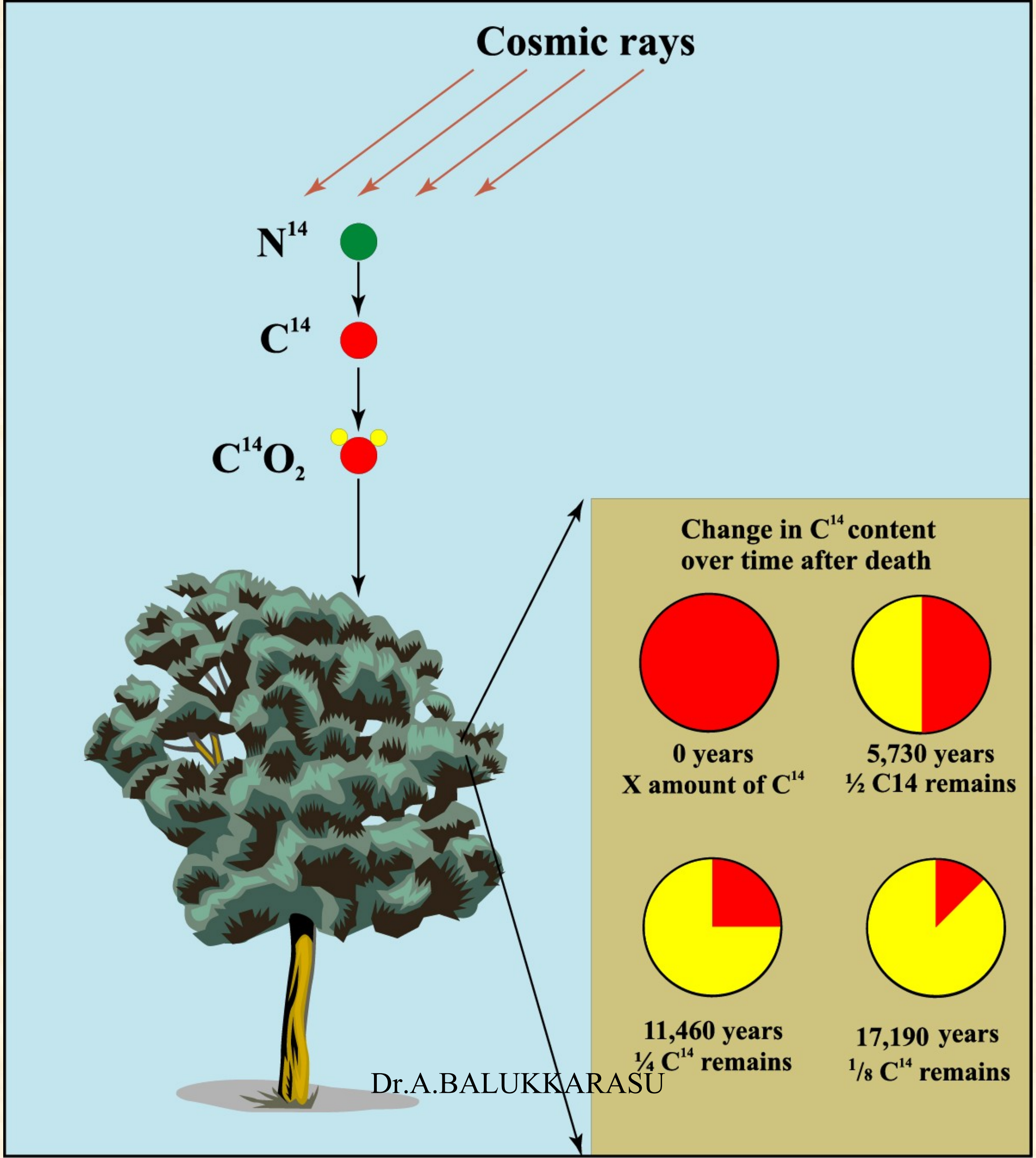
C^{12} and C^{14} are oxidized to form carbon dioxide (CO_2) which is absorbed by organisms.

The concentration of C^{14} in organic tissue is exactly that in the atmosphere.

Upon death, the organisms no longer take in C^{14} and the radiometric clock begins to tick.

The half-life of C^{14} is 5,730 years.

The N^{14} daughter is indistinguishable from natural N^{14} so it is the absolute concentration of C^{14} that is used to determine the age of organic material.



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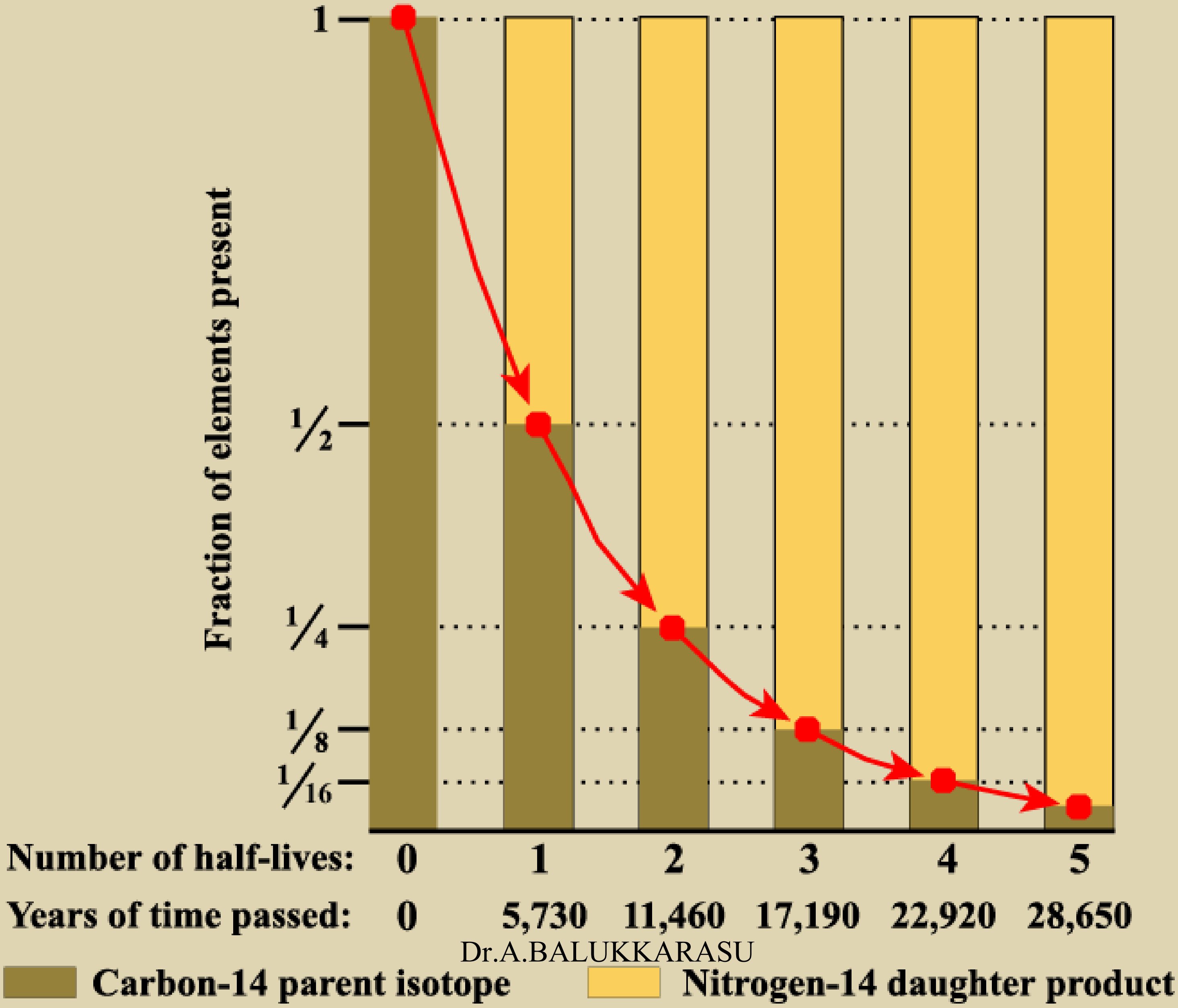
Radioactive decay of C^{14}



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The practical limit for C^{14} dating is about 60,000 years, beyond that there is too little of the parent left to measure.

Radiocarbon dates are reported as "Years BP", where BP stands for "Before Present".

BP actually means, before about 1950.

Prior to 1950 the concentration of C^{14} in the atmosphere was constant.

However, after 1950 the concentration rose significantly due to atmospheric nuclear testing.

Important points regarding radioactive dating!

A radiometric date is always the time elapsed since the isotope was locked into the rock.

Igneous rock: time of crystallization.

Metamorphic rock: time since cooling.

Chemical sedimentary mineral: time since precipitation.

Clastic sedimentary rocks: age of mineral grains.

e.g., K^{40} date would be the age of feldspars in the sediment, **not** the age of deposition of the sediment.

Organic material: the time since the organism lived.

Error in radiometric dates

If atoms of the parent element are added to the rock.

E.g., groundwater percolating through rock can introduce younger atoms. The resulting date would underestimate the age of the rock.

Daughter products are lost.

E.g., Ar^{40} is a gas. If the rock is heated up the gas escapes.

Groundwater passing through the rock may remove daughter product atoms.

In either case, the resulting date would then be younger than the true age.

Therefore, only pristine rocks can be dated.

Important Radiometric Dates in Earth History

Oldest Earth rocks: 4.02 billion years

Oldest moon rocks: 3.5-4.2 billion years

Oldest Meteorite: approx. 4.5 billion years

Planet formation: approx. 5 billion years (completion by 4.56 BY).

Oldest oceanic crust: 180 million years.
(all older crust has been subducted)

Oldest fossils: 3.5 billion years (algae and bacteria)

Oldest shelled fossil: 550 million years.

Relative Time

The estimation of the age of rocks *relative* to the age of other rocks.

The Geologic Time Scale was originally based on just such a classification of rocks.

Relies on:

Regional mapping of geologic strata worldwide.

Determination of their lateral and vertical distribution.

Identification of the fossils that they contain.

The modern scale benefits from radiometric dates of datable rocks.

Basic Principles (Nicholas Steno)

Steno mapped rock in the vicinity of Rome in the 17th century.

He developed a set of principles for determining the age of rocks, faults, and unconformities relative to each other.

Principle of superposition

Layered sedimentary rocks become younger upwards.

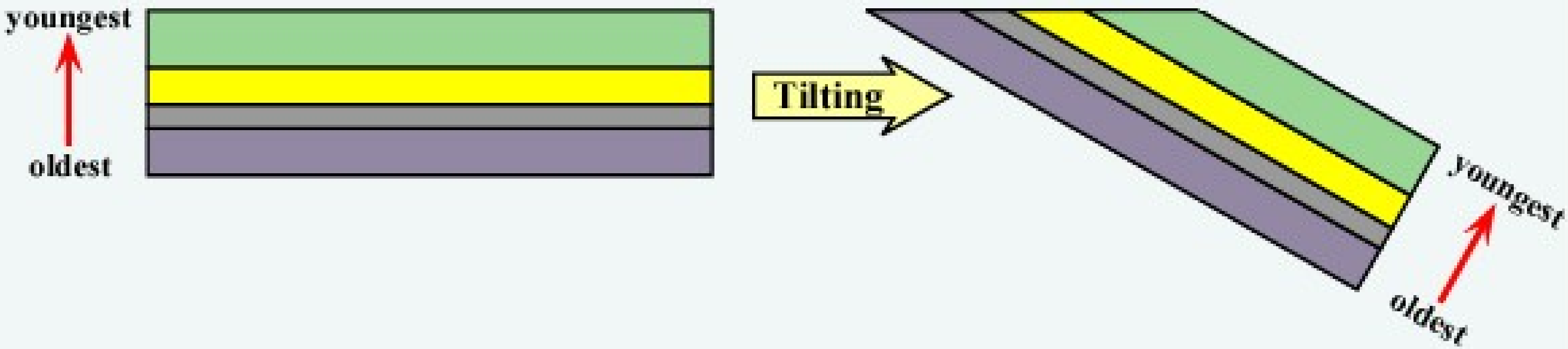
1. Principle of Superposition

In a sequence of undisturbed strata, the oldest strata are lowest in the sequence and the strata become younger upwards.

Principle of original horizontality

Layered rocks are originally deposited in a horizontal position (therefore any tilting post-dates deposition).

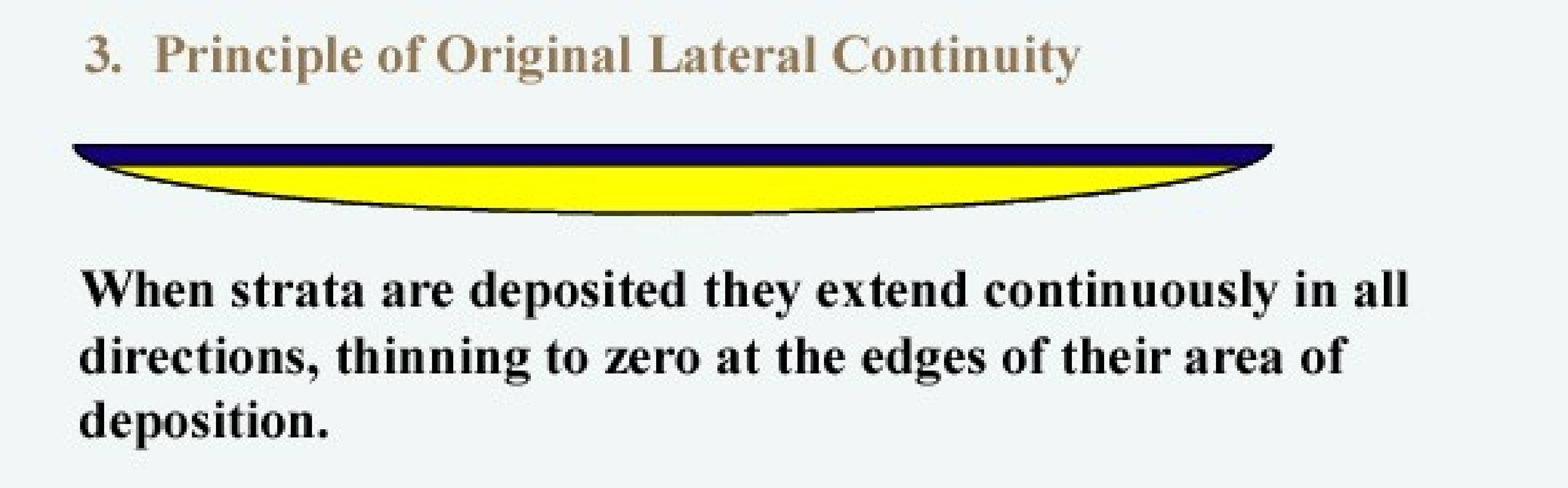
2. Principle of Original Horizontality



All strata are deposited in a nearly horizontal position. If strata are found to be dipping or folded, then tilting must have taken place some time after deposition.

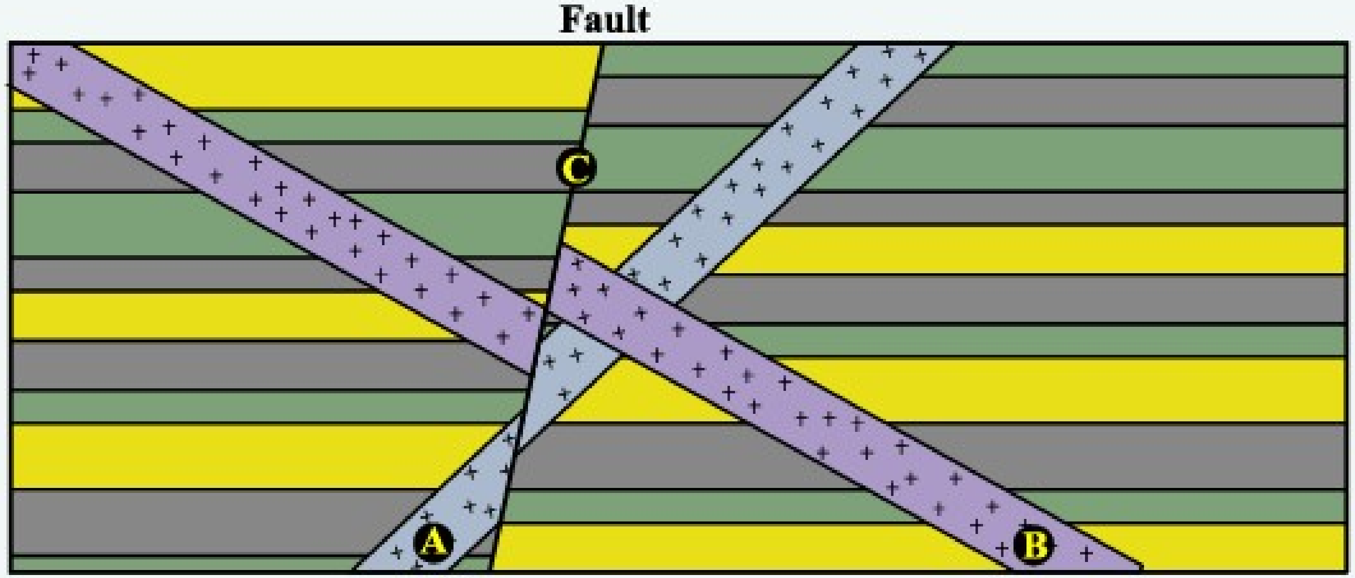
Principle of original lateral continuity

When strata are deposited they extend continuously in all directions but thin to zero at the edge of their area of deposition.



A fourth important principle, not attributed to Steno:

Principle of cross-cutting relationships

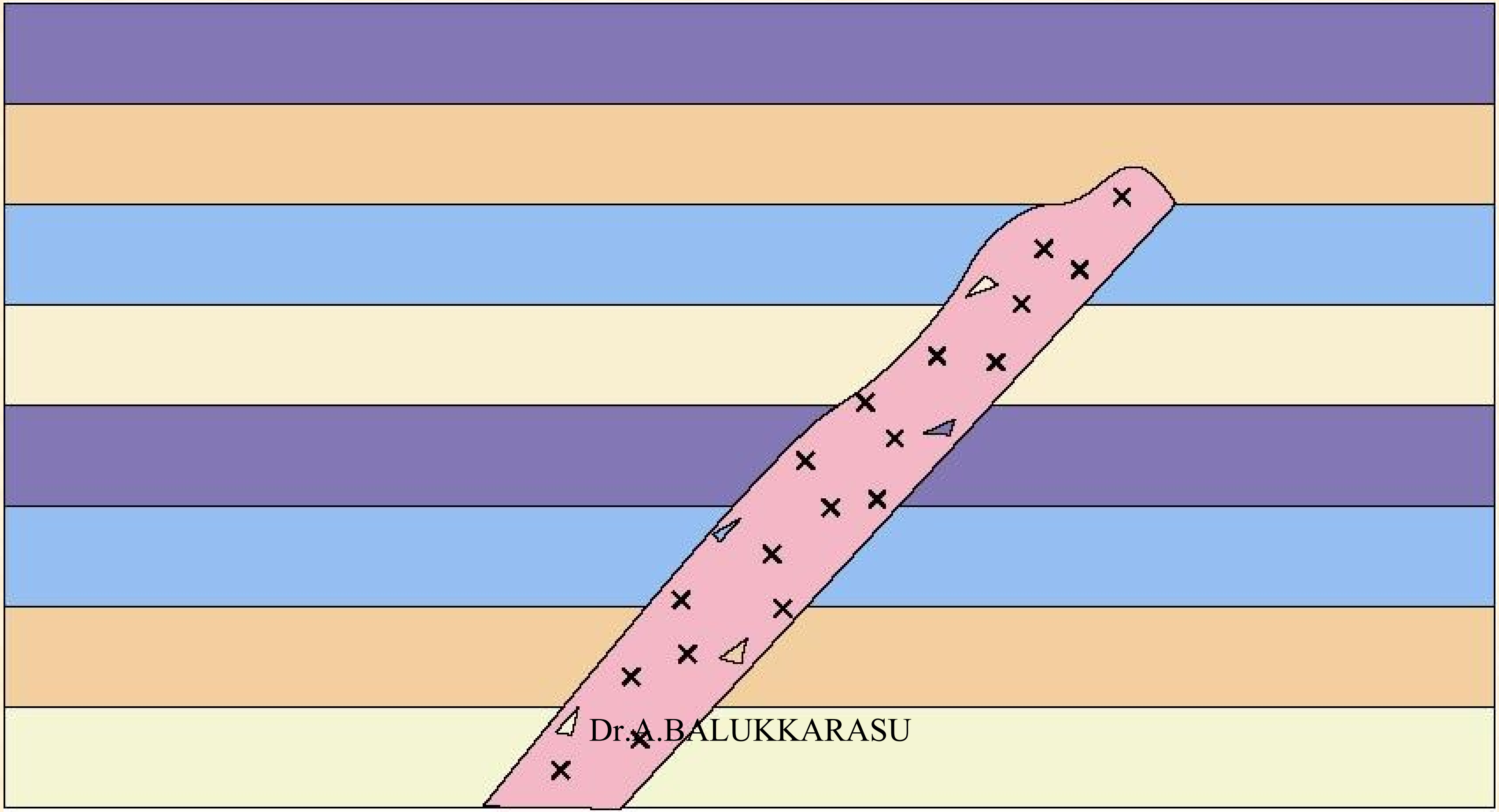


A rock (or fault) is younger than any rock (or fault) through which it cuts.

In this example the horizontal strata were deposited and subsequently intruded: intrusion A is older than intrusion B and both are older than fault C.

A fifth principle:

Rocks fragments that are included in an igneous intrusion or sediment are older than the intrusive rocks or sediment containing them.



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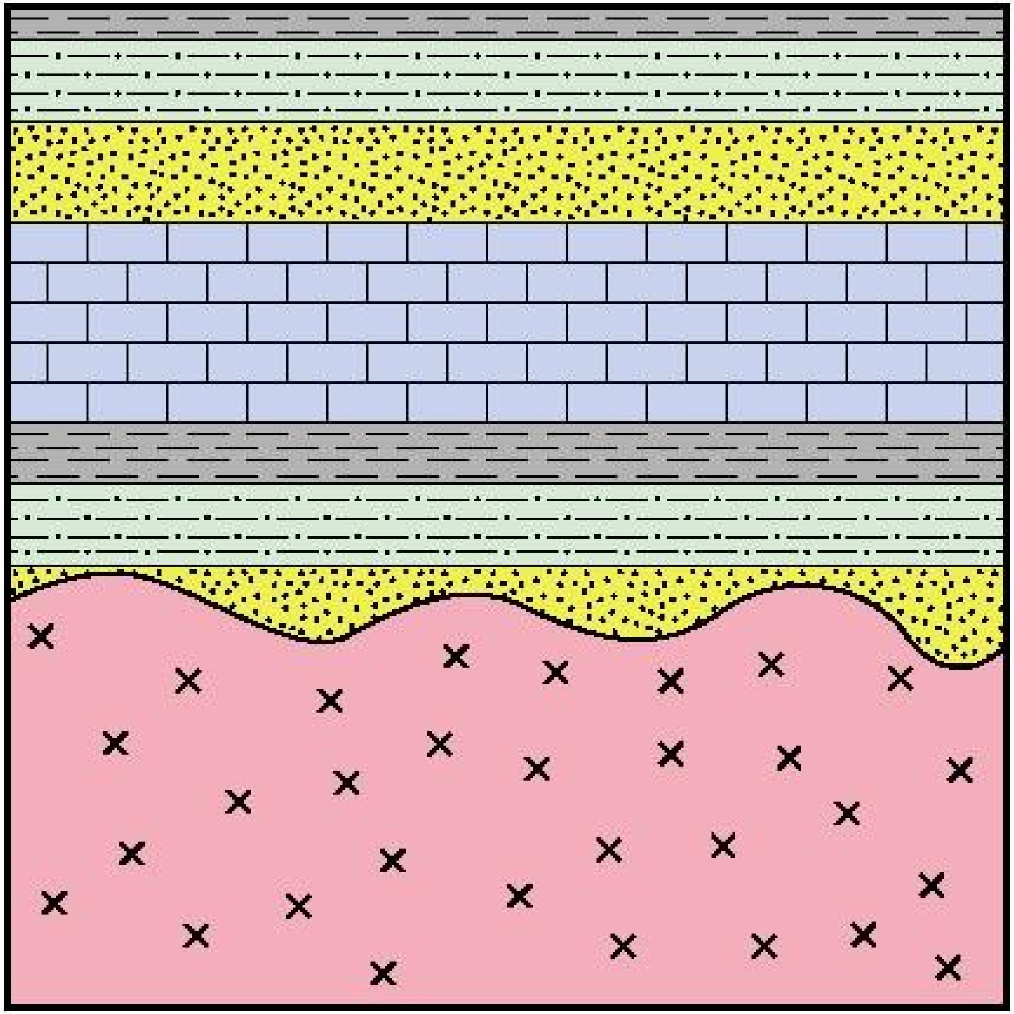
Yet a sixth principle:

Erosional unconformities are **younger** than the rocks that they affect.

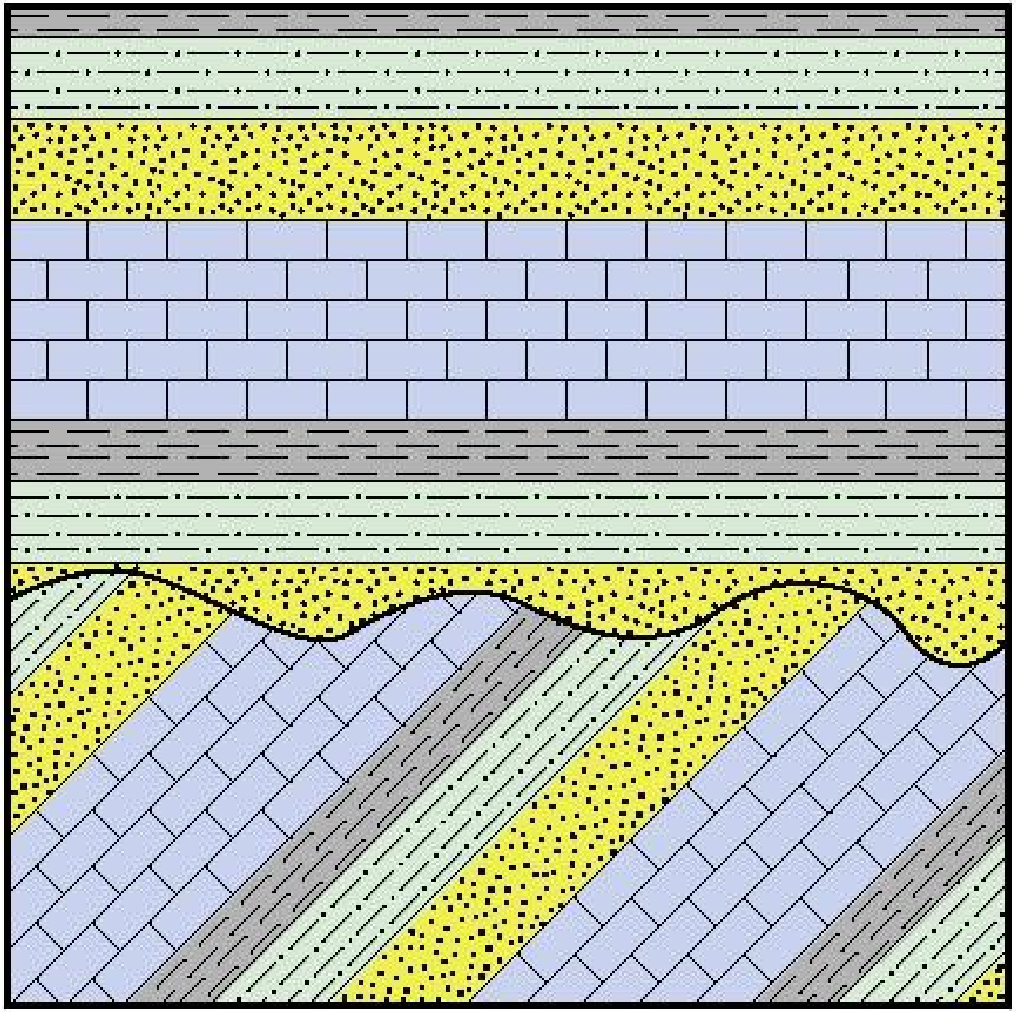
A surface of erosion or non-deposition separating younger strata from older rocks.

Nonconformity



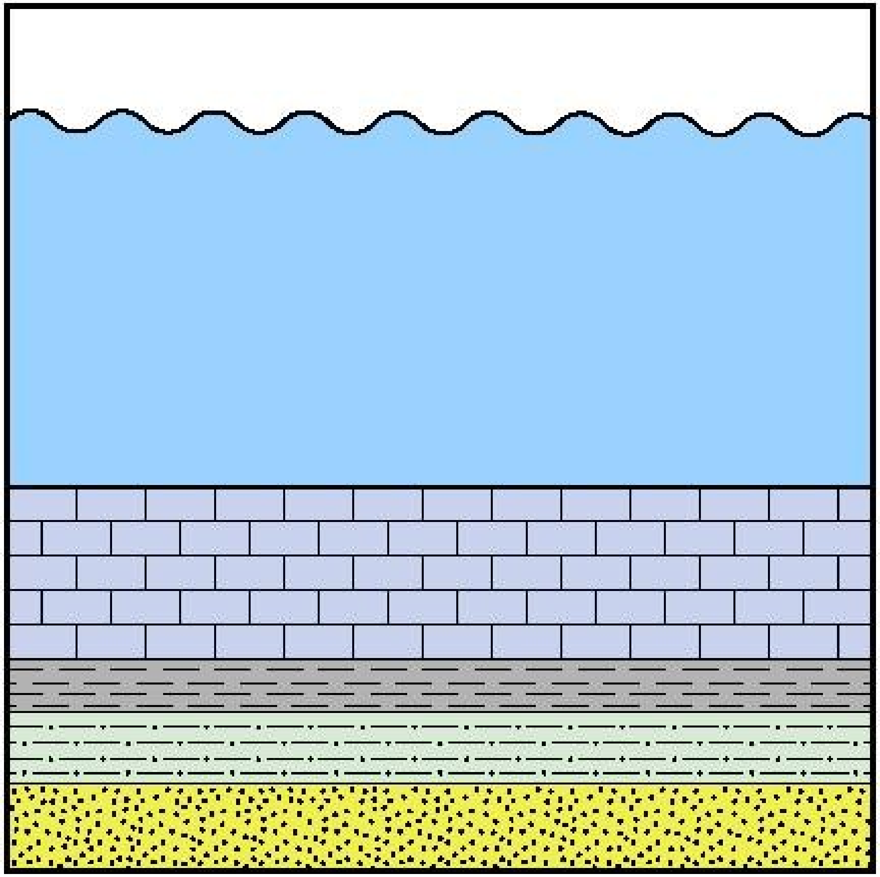
Sedimentary strata are deposited on an eroded surface on igneous or metamorphic rocks.

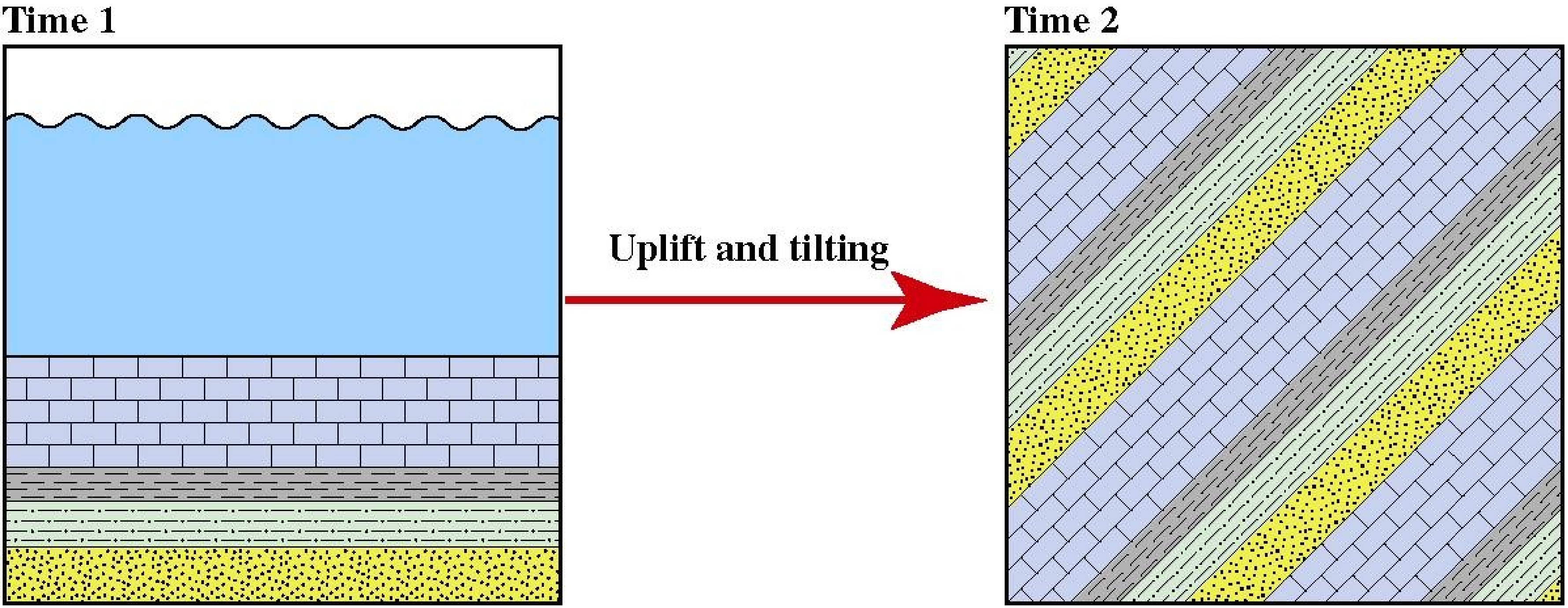
Angular unconformity

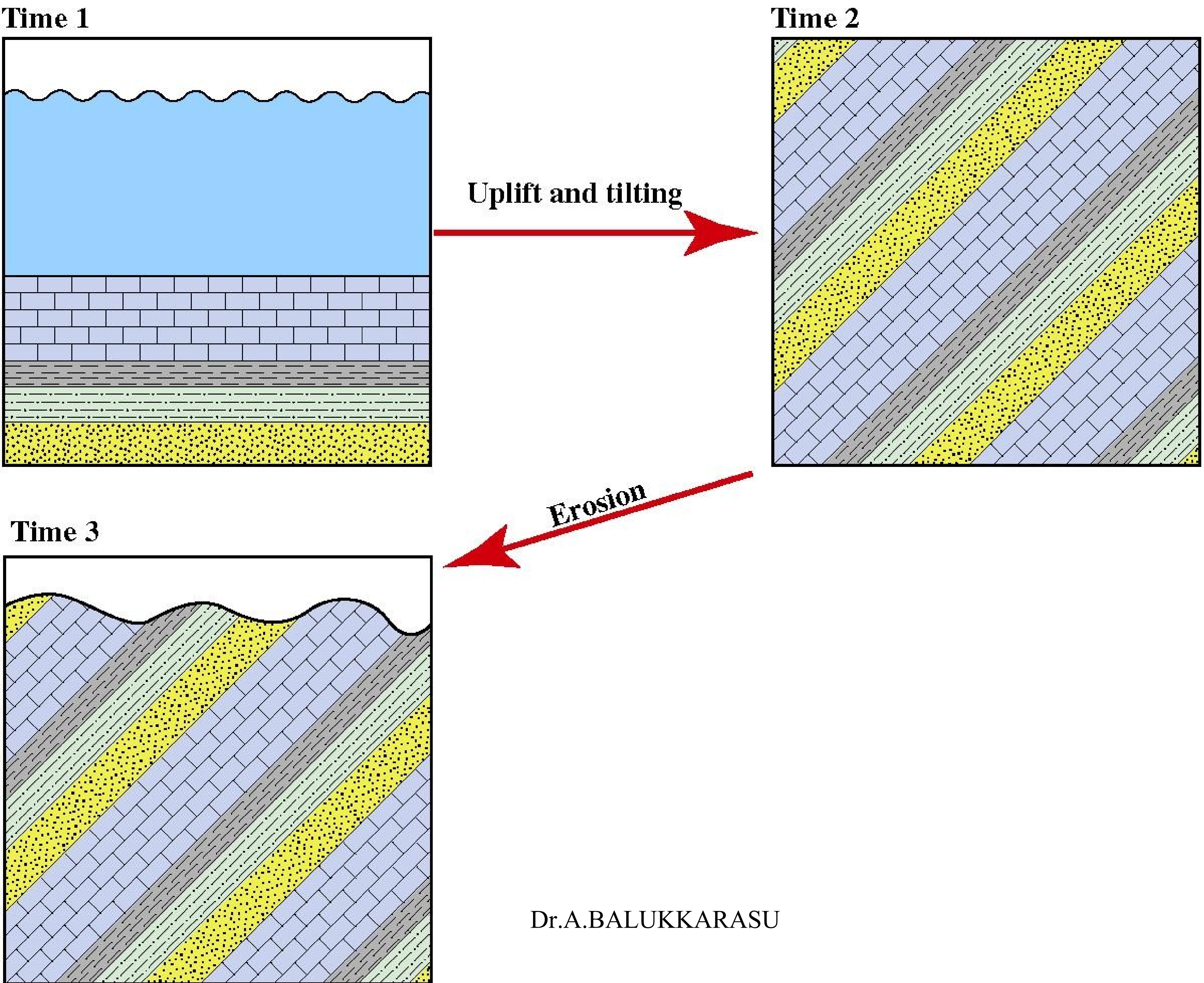


Sedimentary strata are deposited on older strata which have been deformed and eroded.

Time 1




Time 1
Uplift and tilting
Time 2



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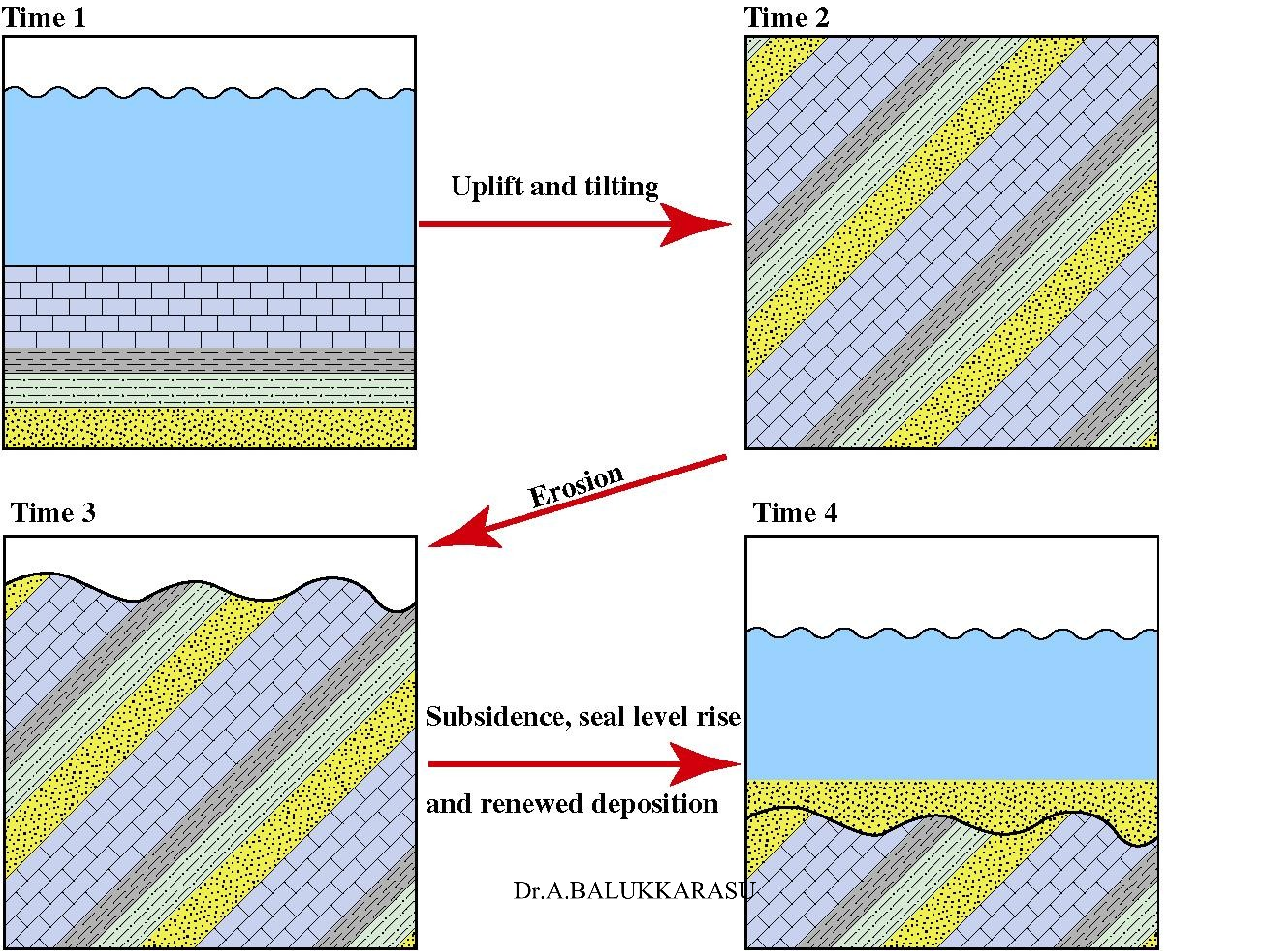
Time 1
Uplift and tilting
Time 2
Erosion
Time 3
Time 4
Subsidence, seal level rise
and renewed deposition
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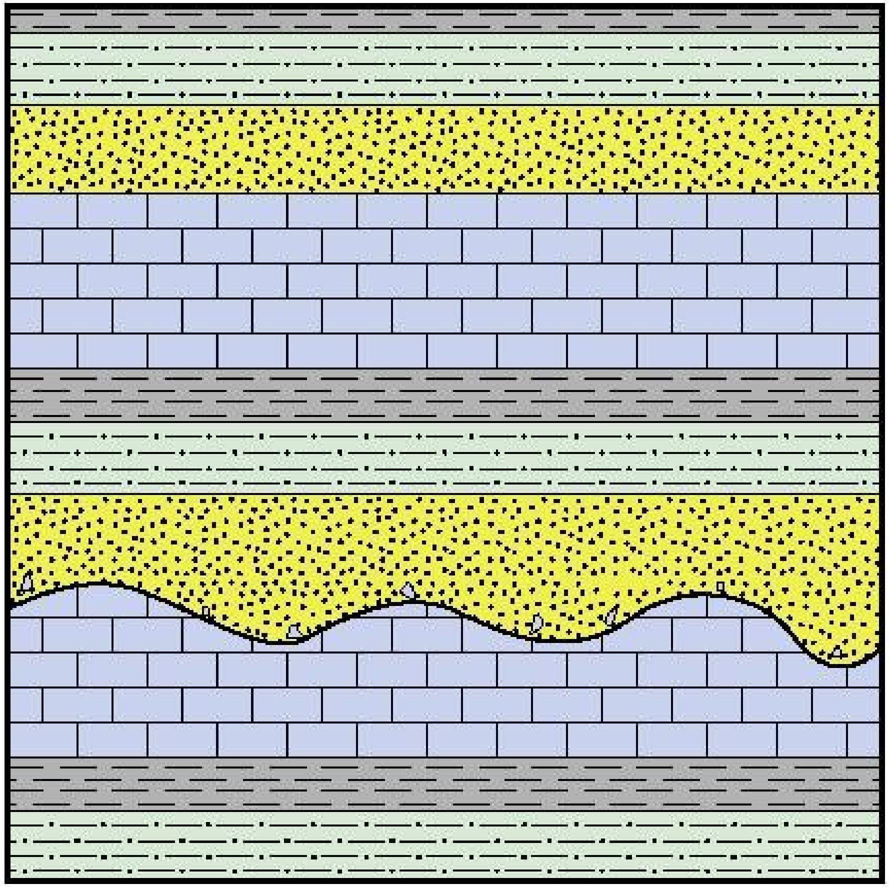
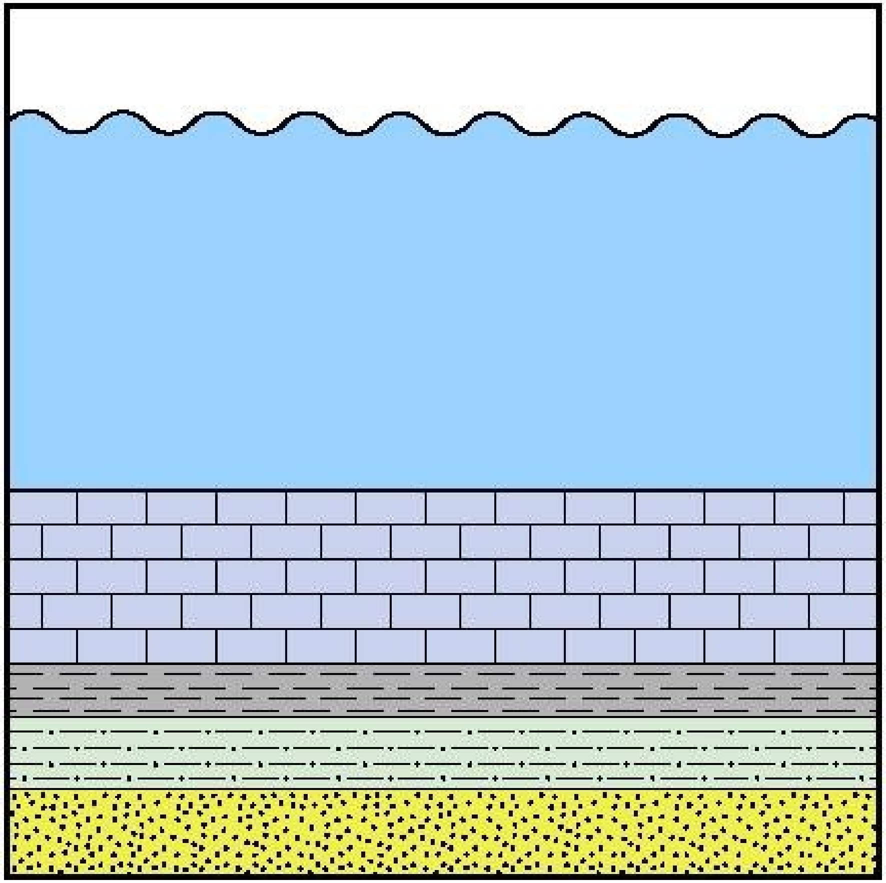
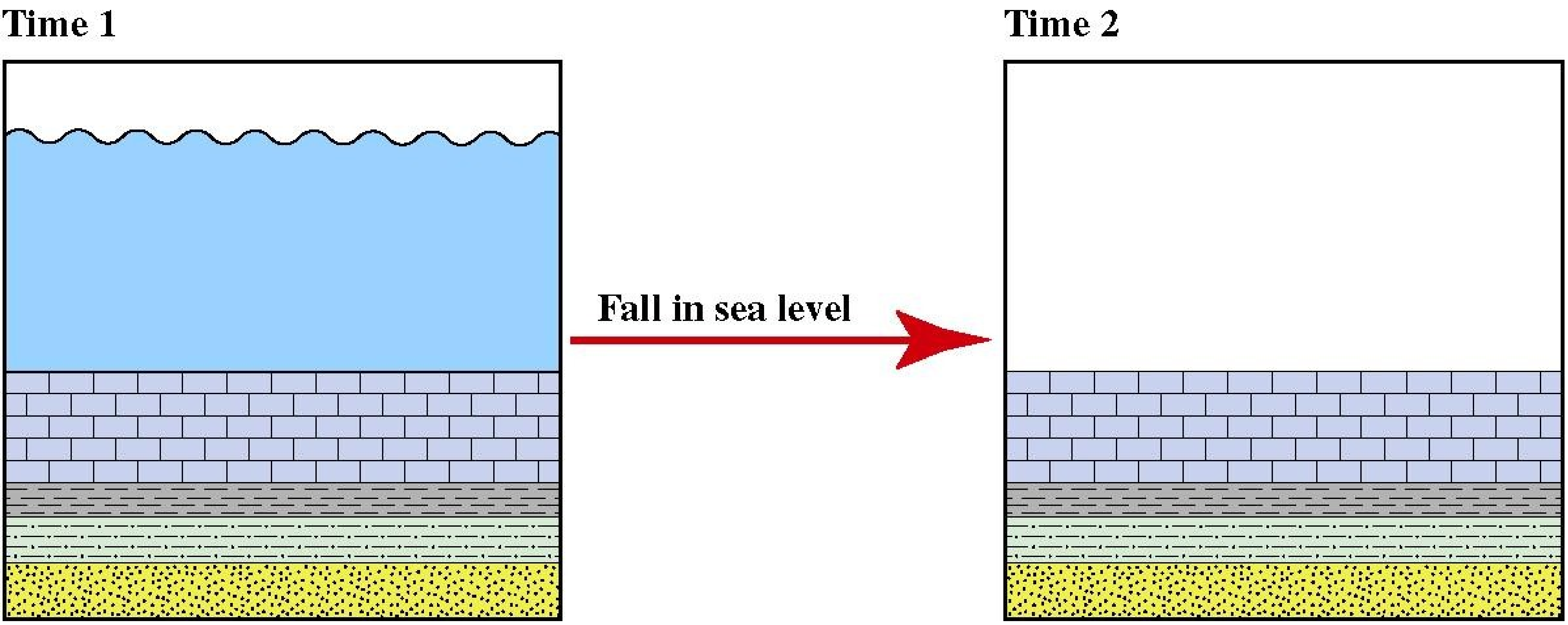
Disconformity



Sedimentary strata are deposited older, undeformed strata that have undergone erosion. Note that inclusions of older

Time 1





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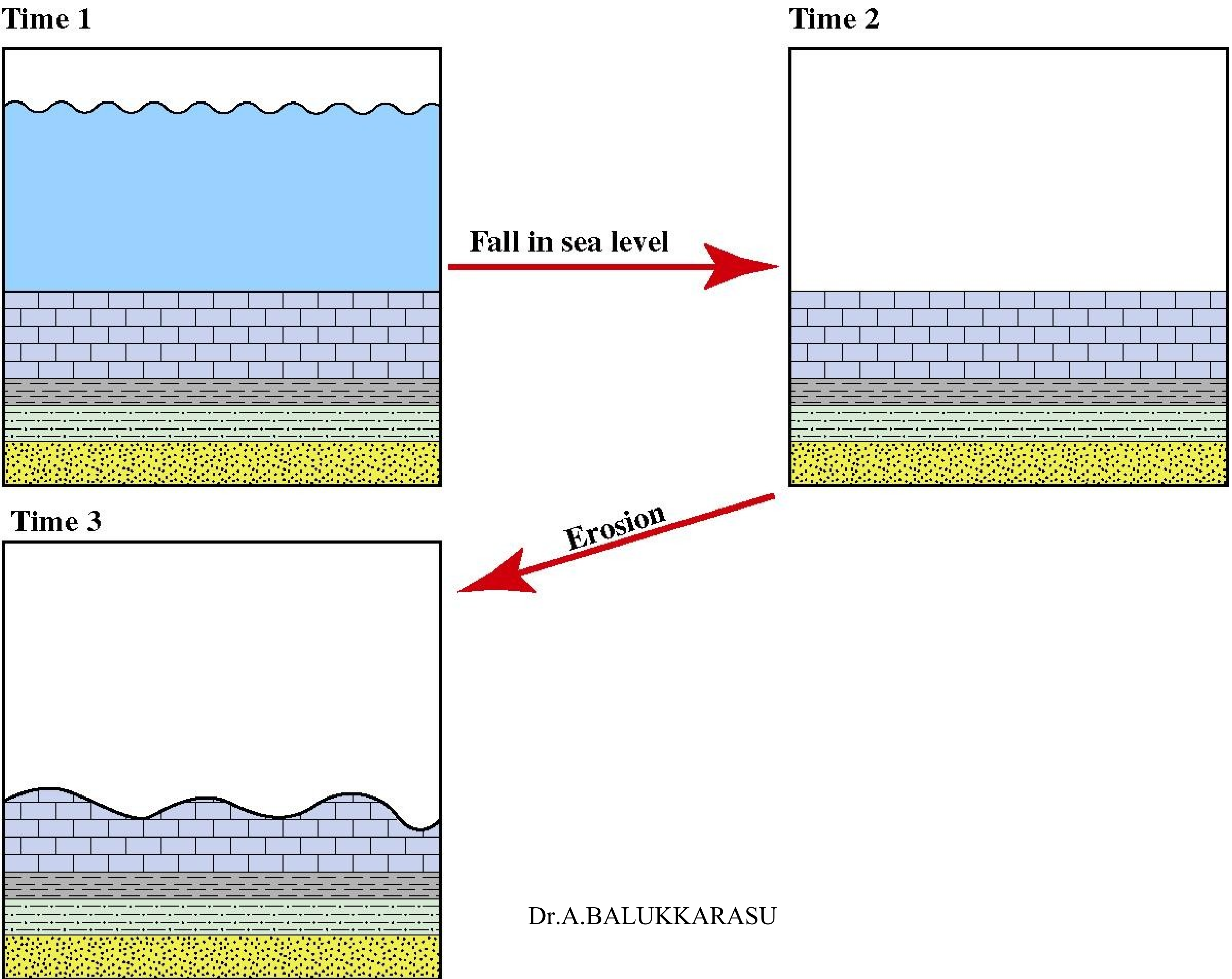

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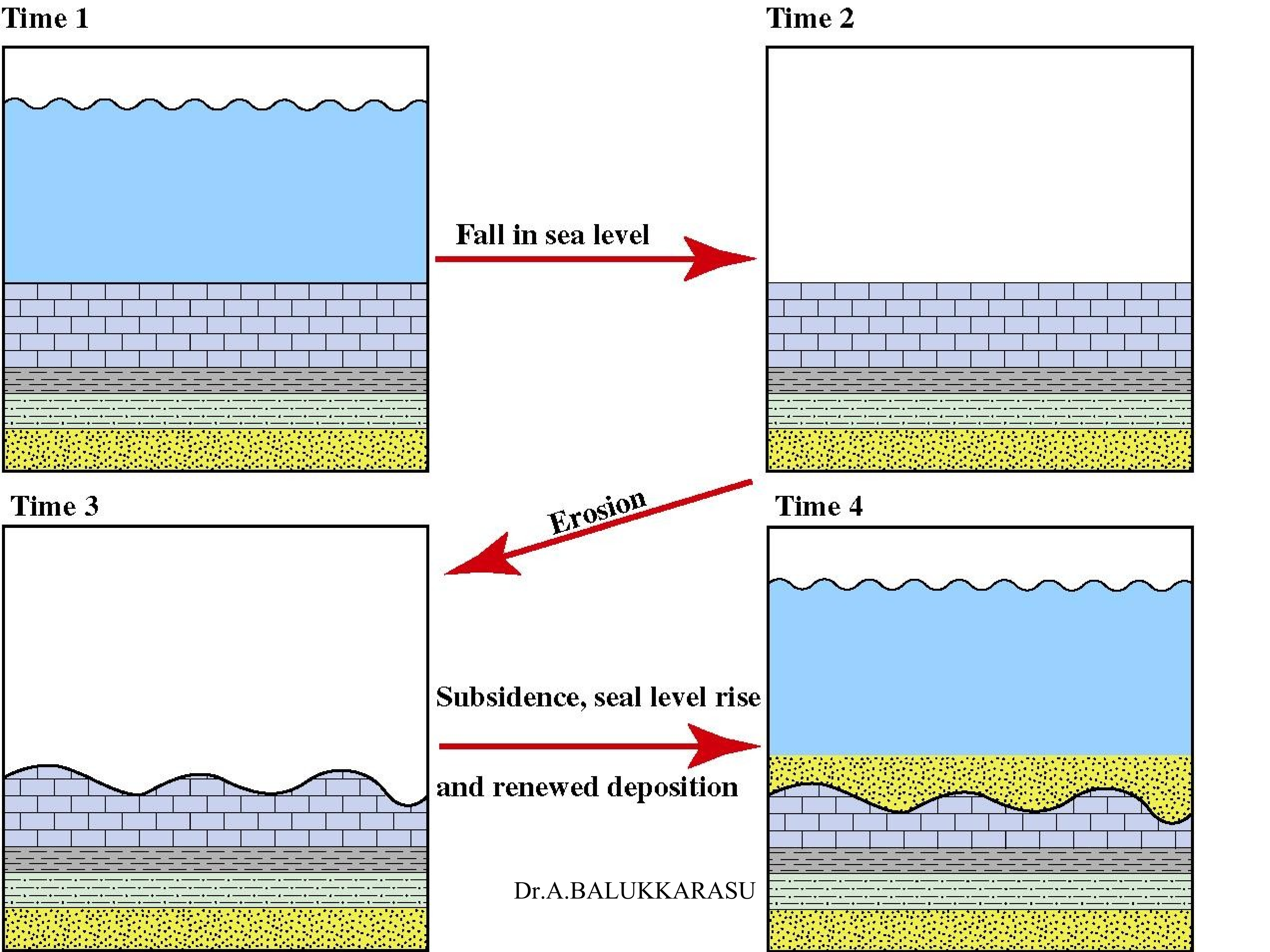
Time 1
Time 2
Fall in sea level
Erosion
Time 3
Time 4
Subsidence, seal level rise
and renewed deposition
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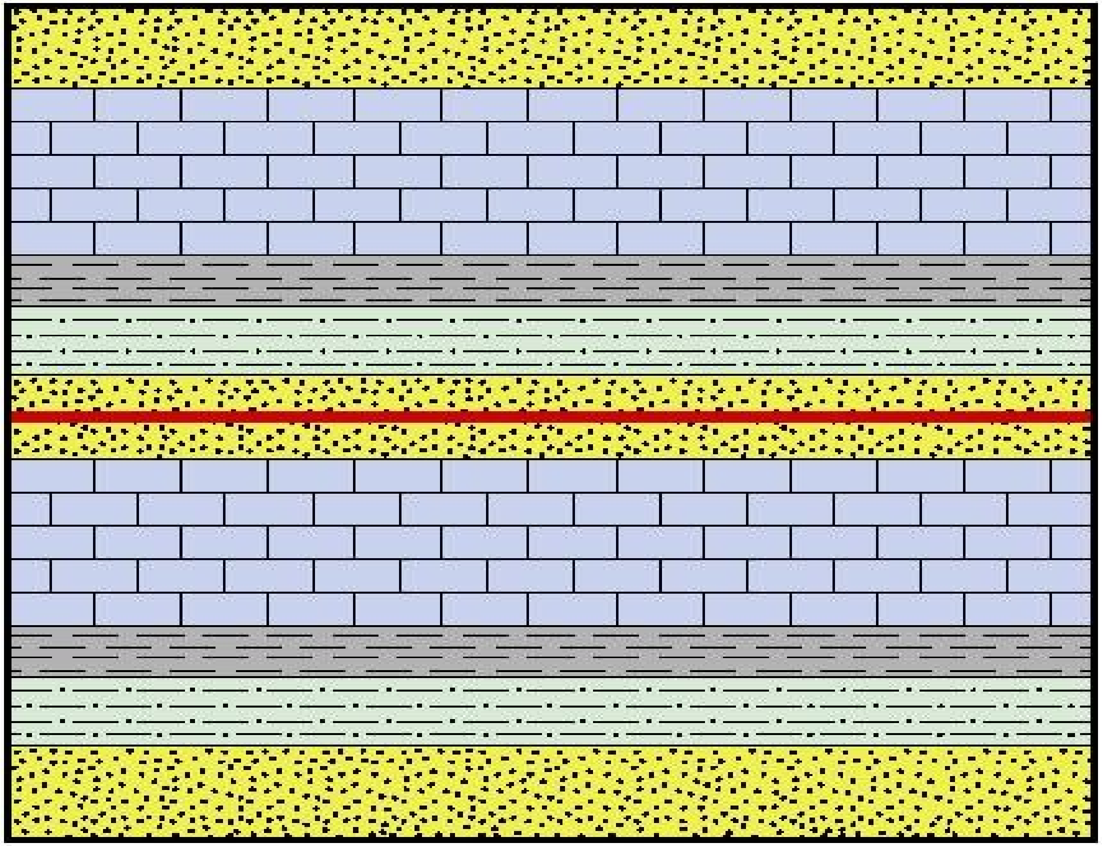
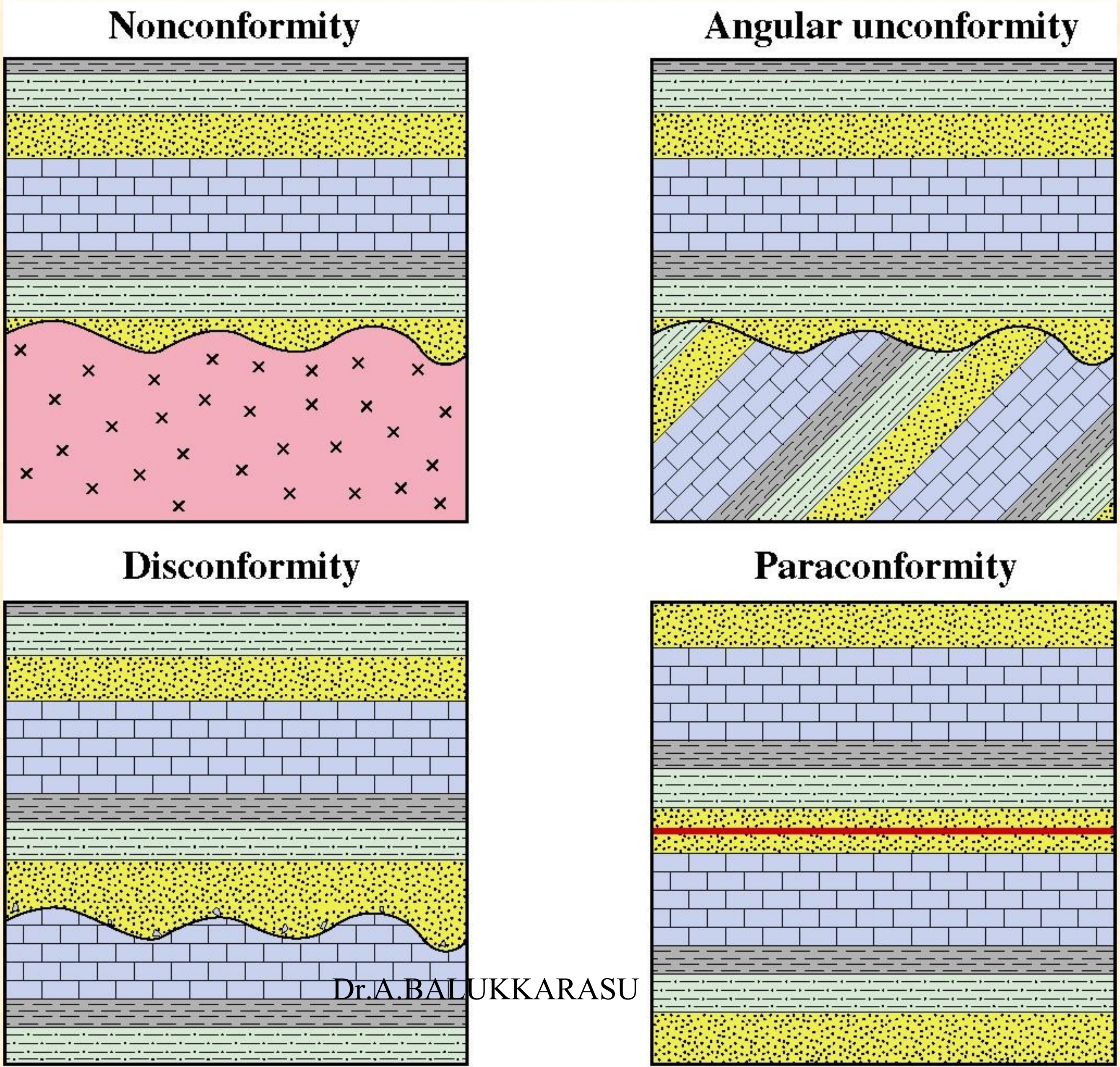
Paraconformity



Sedimentary strata are deposited on older, underformed strata. There is no evidence of erosion but missing fossils indicate either erosion or a period of non-deposition (a hiatus) has taken place at the unconformity.

Erosional unconformities are **younger** than the rocks that they affect.



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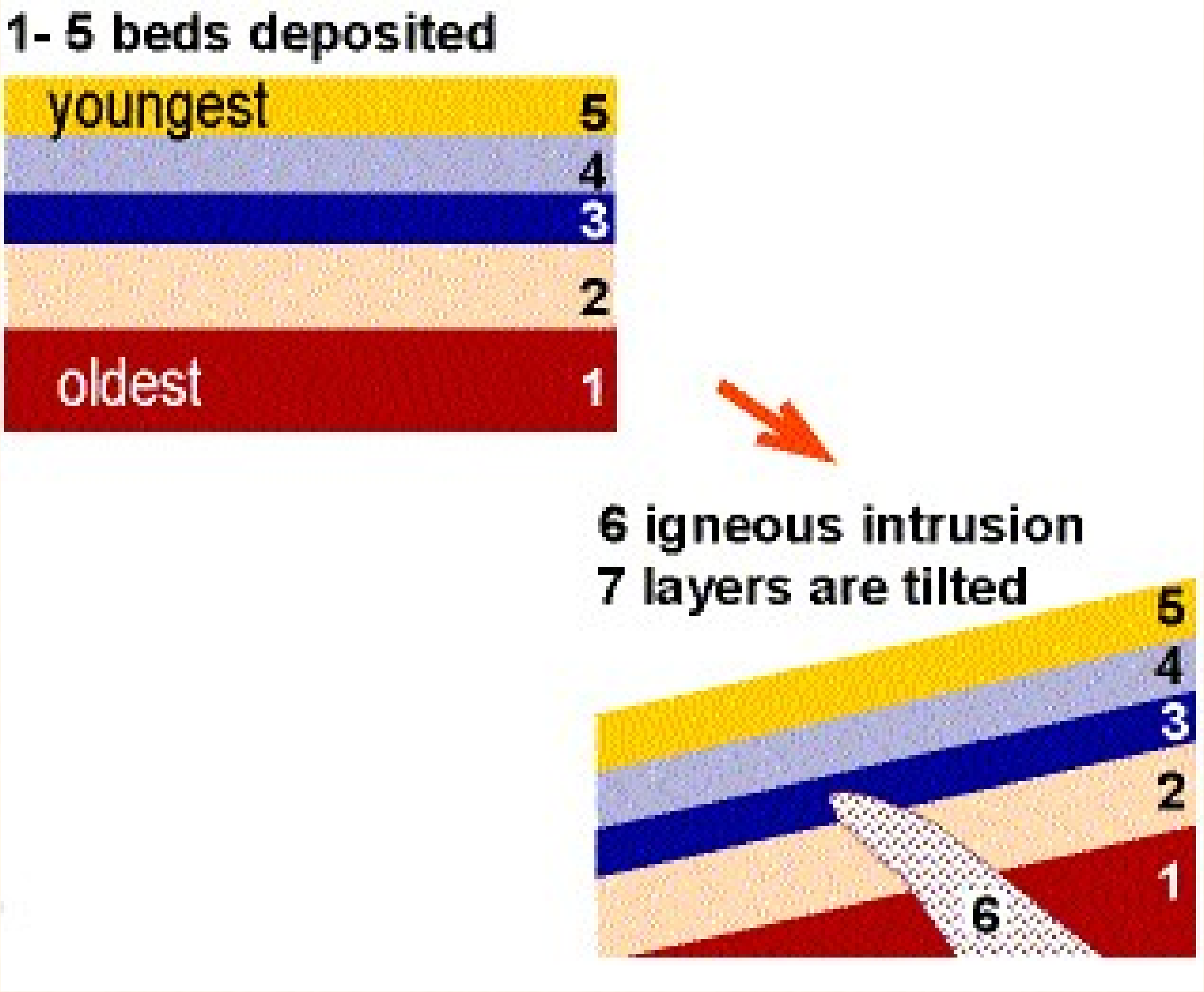
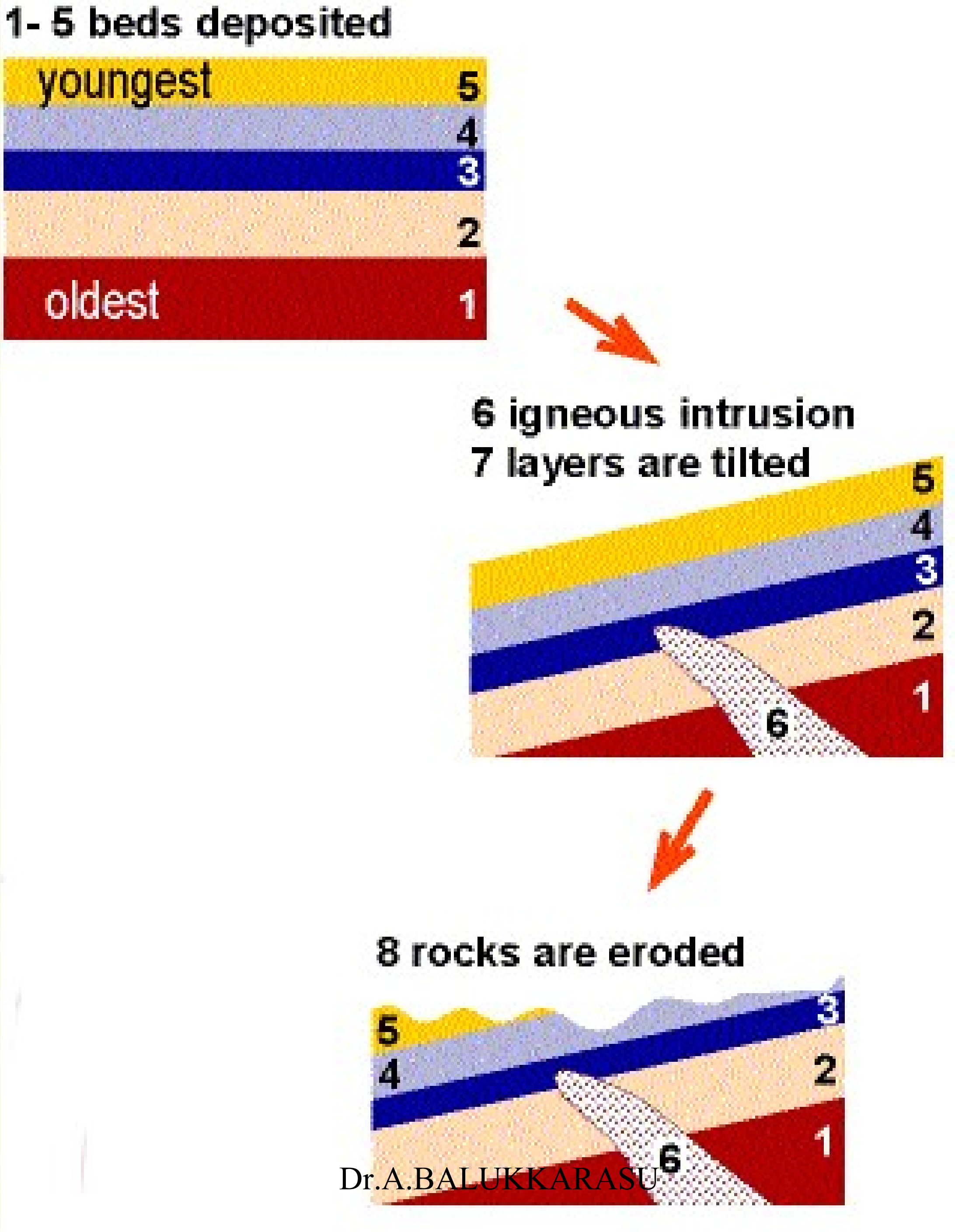
With these six principles we can determine the relative times when sedimentary rocks were deposited, when folding takes place, when erosional events took place, when igneous intrusion occurred and when faulting occurred….The sequence of geological events (GEOLOGIC HISTORY)


1- 5 beds deposited
youngest
5
4
3
2
oldest
1


1- 5 beds deposited
youngest
5
4
3
2
oldest
1
6 igneous intrusion
7 layers are tilted
5
4
3
2
1
6



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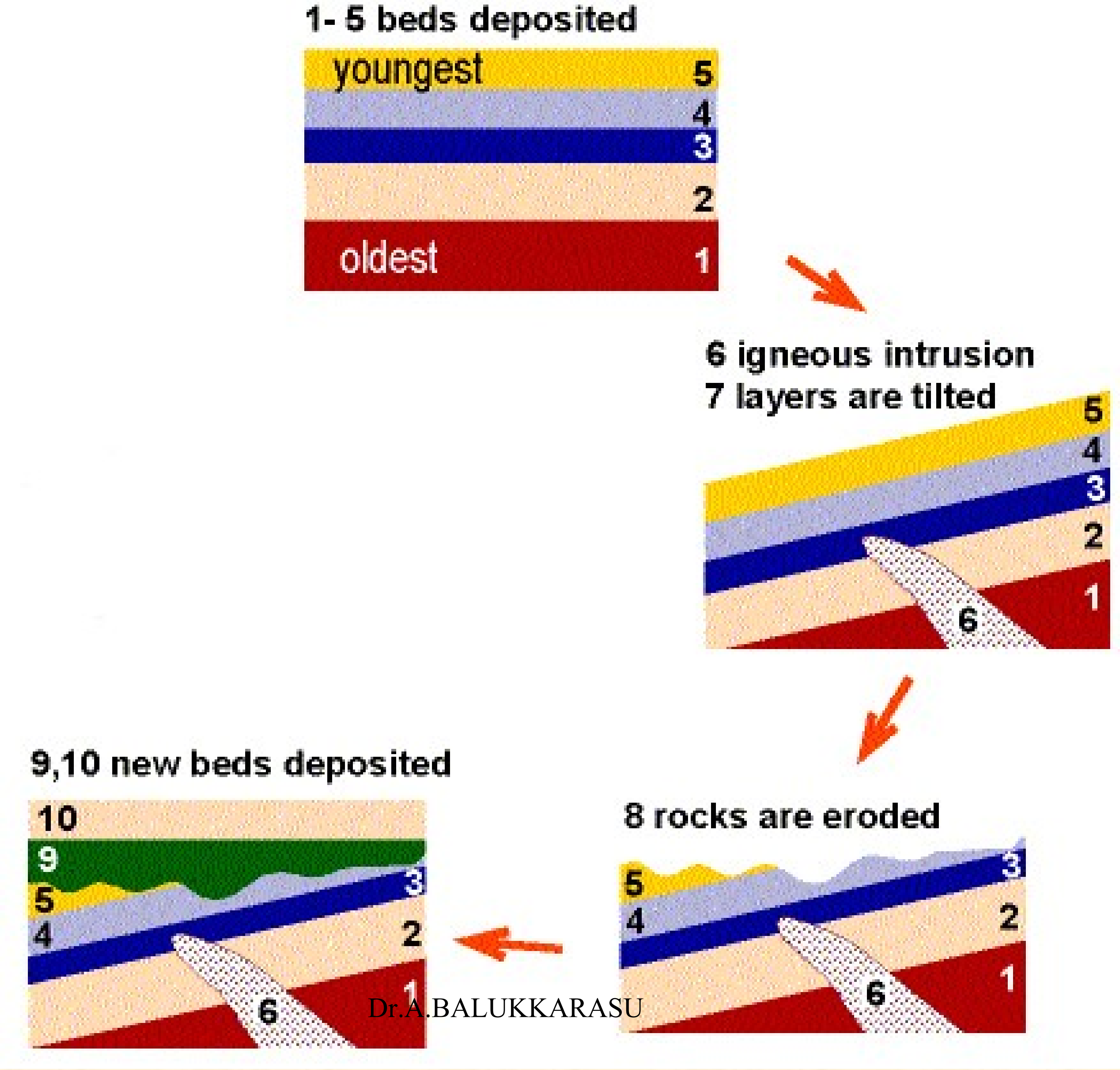

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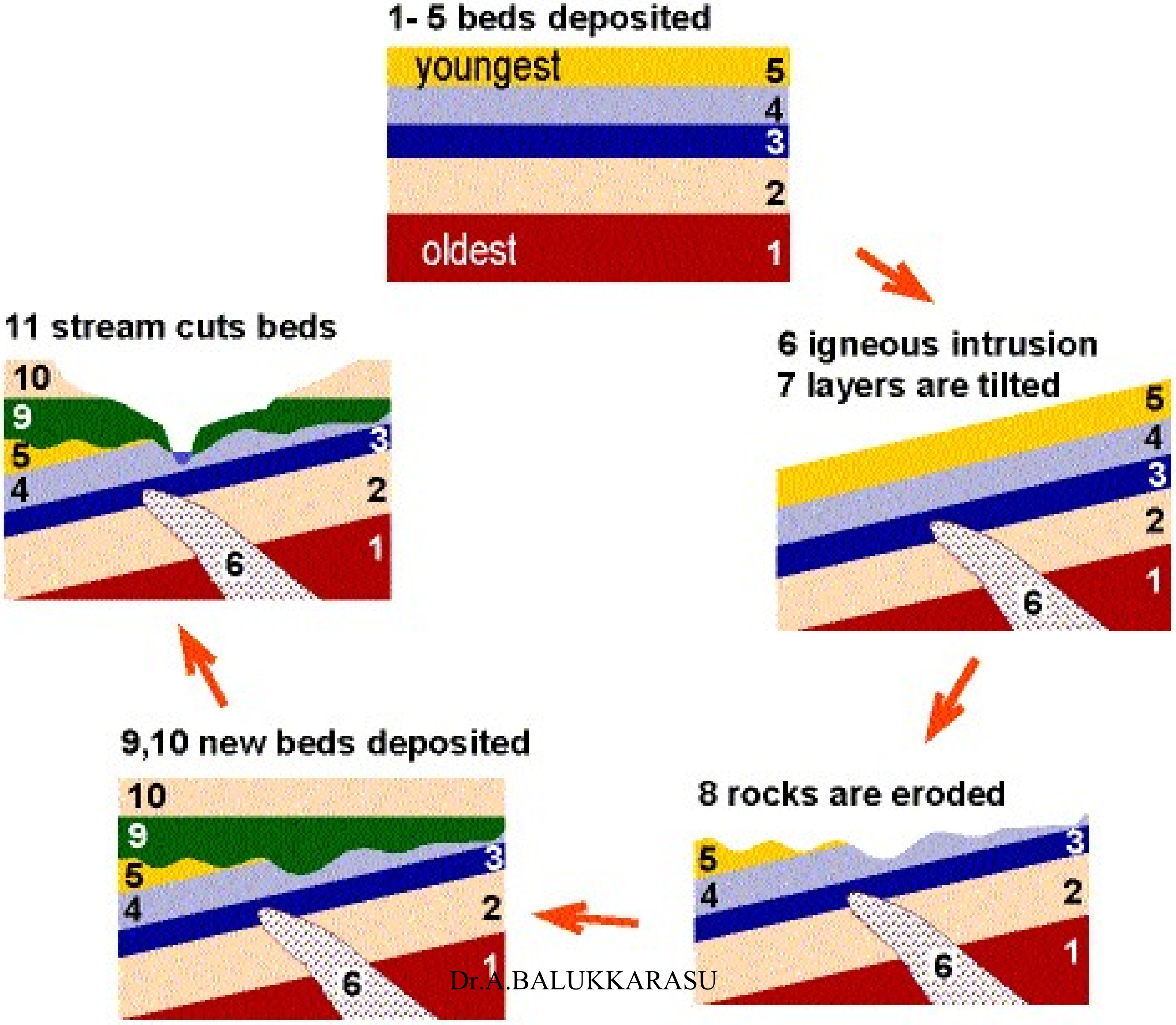

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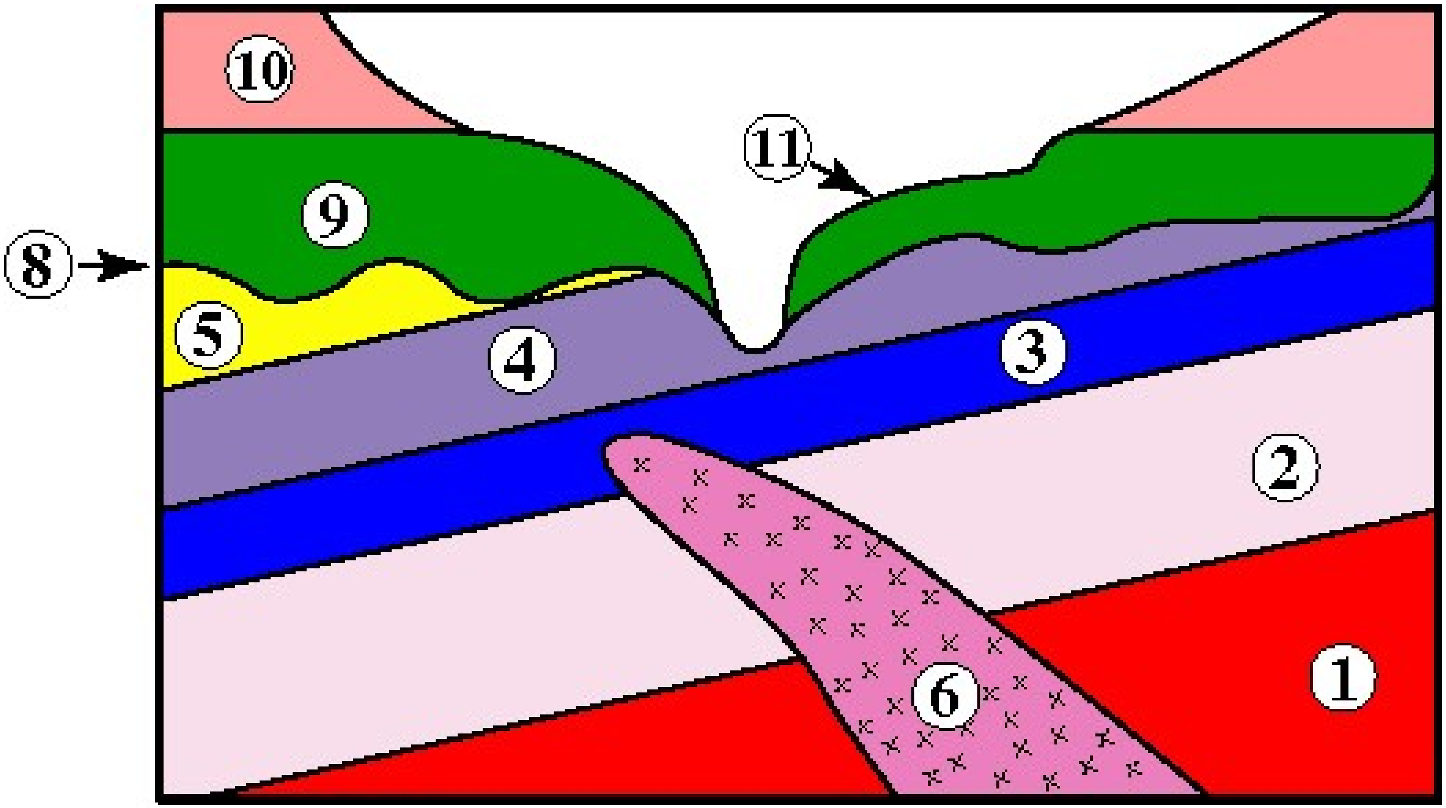
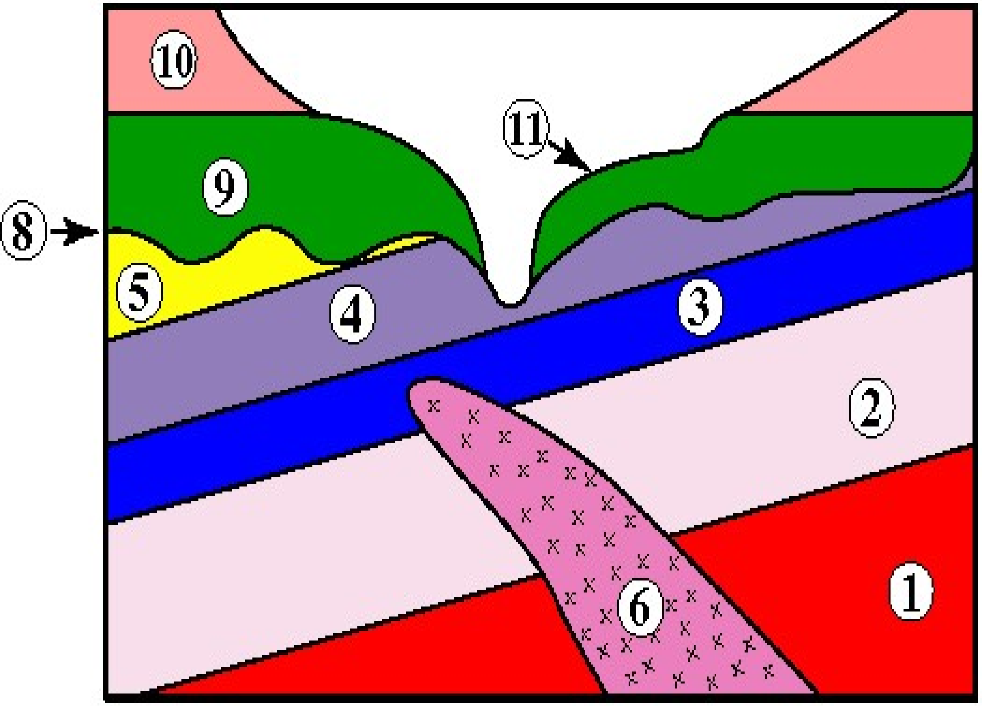
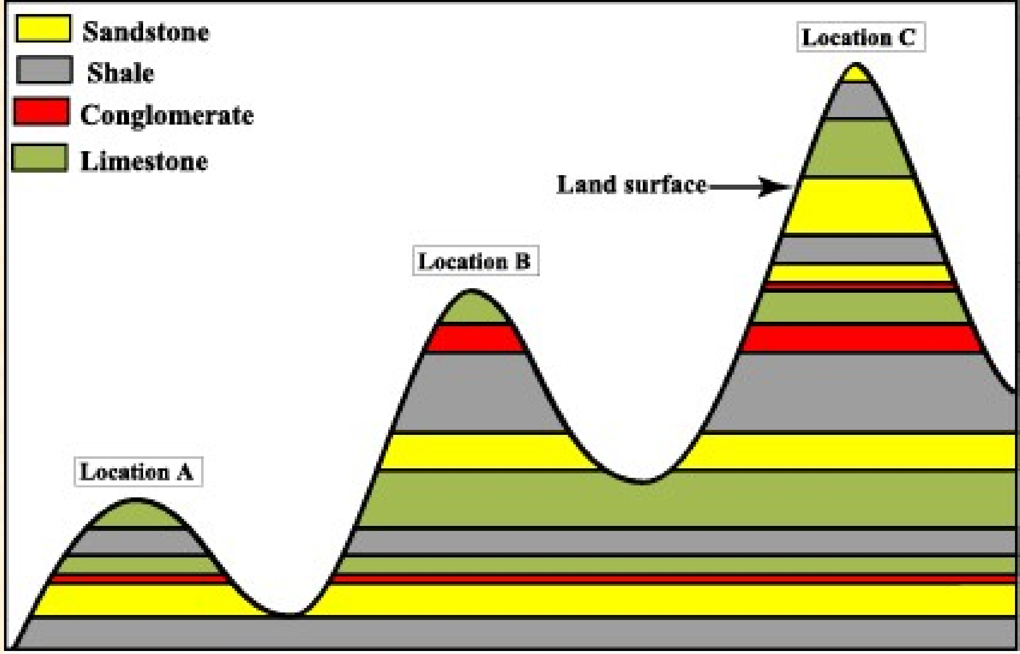

10
11
9
8
5
4
3
2
6
1



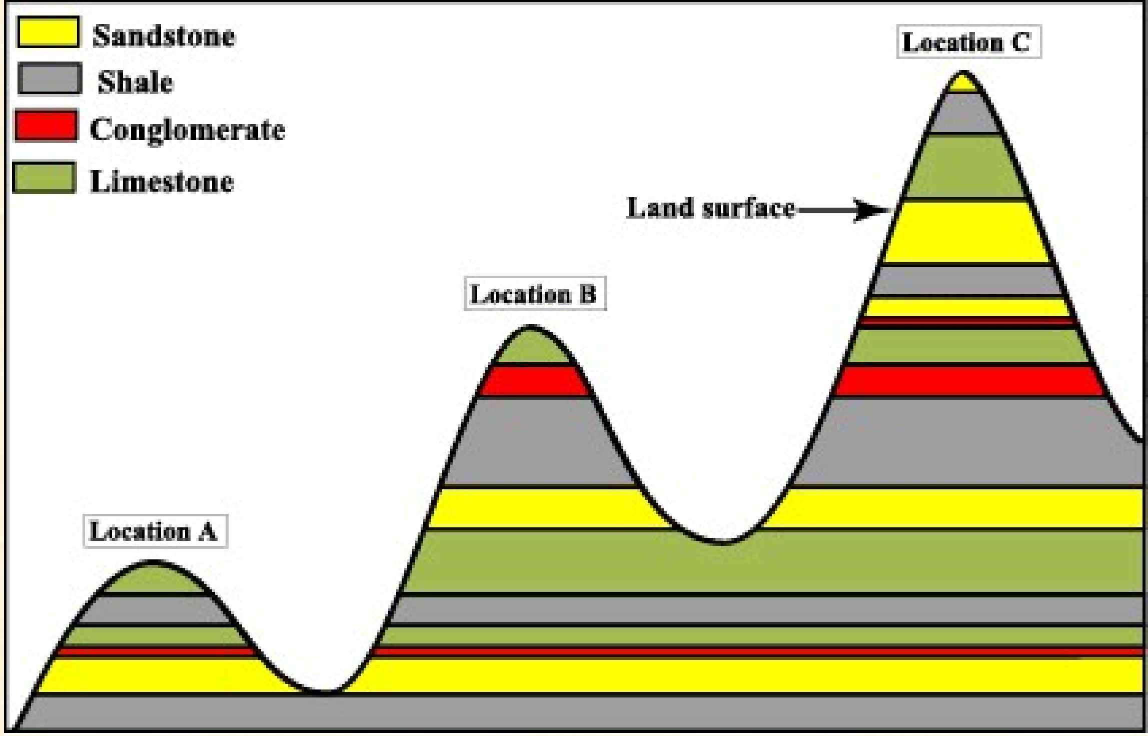
	Sequence of events
First	Deposition of unit 1.
	Deposition of unit 2.
	Deposition of unit 3.
	Deposition of unit 4.
	Depostion of unit 5.
	Intrusion by unit 6.
	Tiltling of units 1 to 5.
	Erosion to form angular unconformity (8)
	Deposition of unit 9.
	Deposition of unit 10.
Last	Erosion of modern land surface (11)

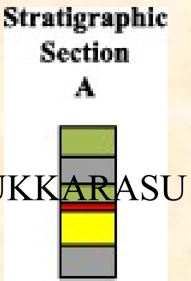
Correlation: the demonstration of **equivalence** of rocks that are geographically separate.

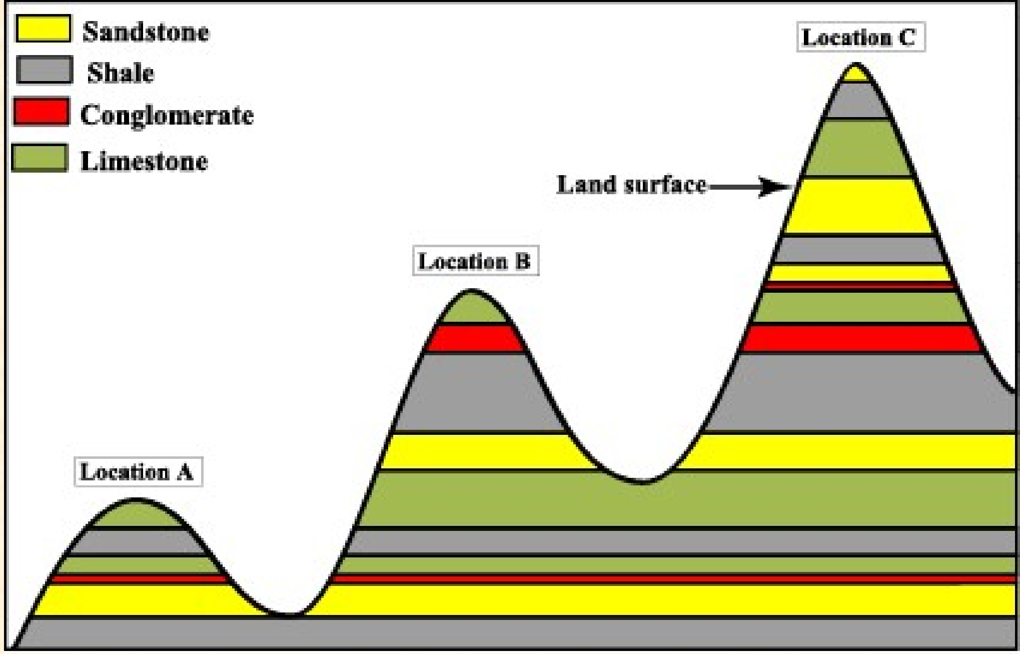


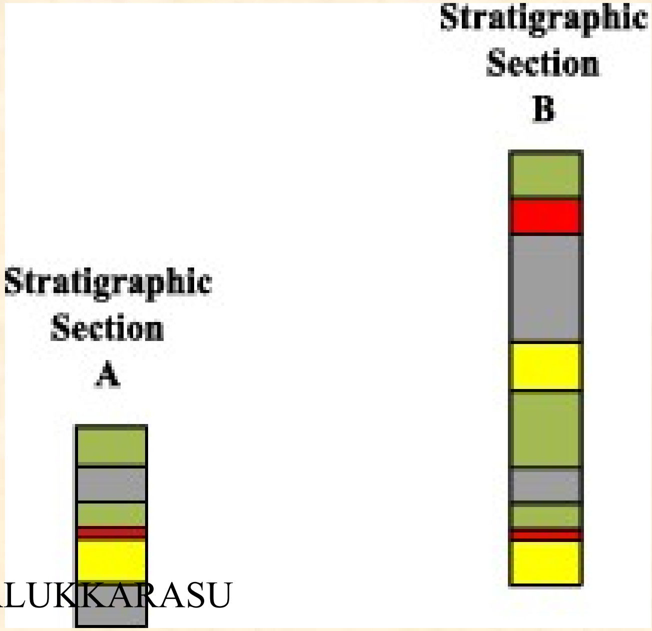
lithological and/or age equivalence

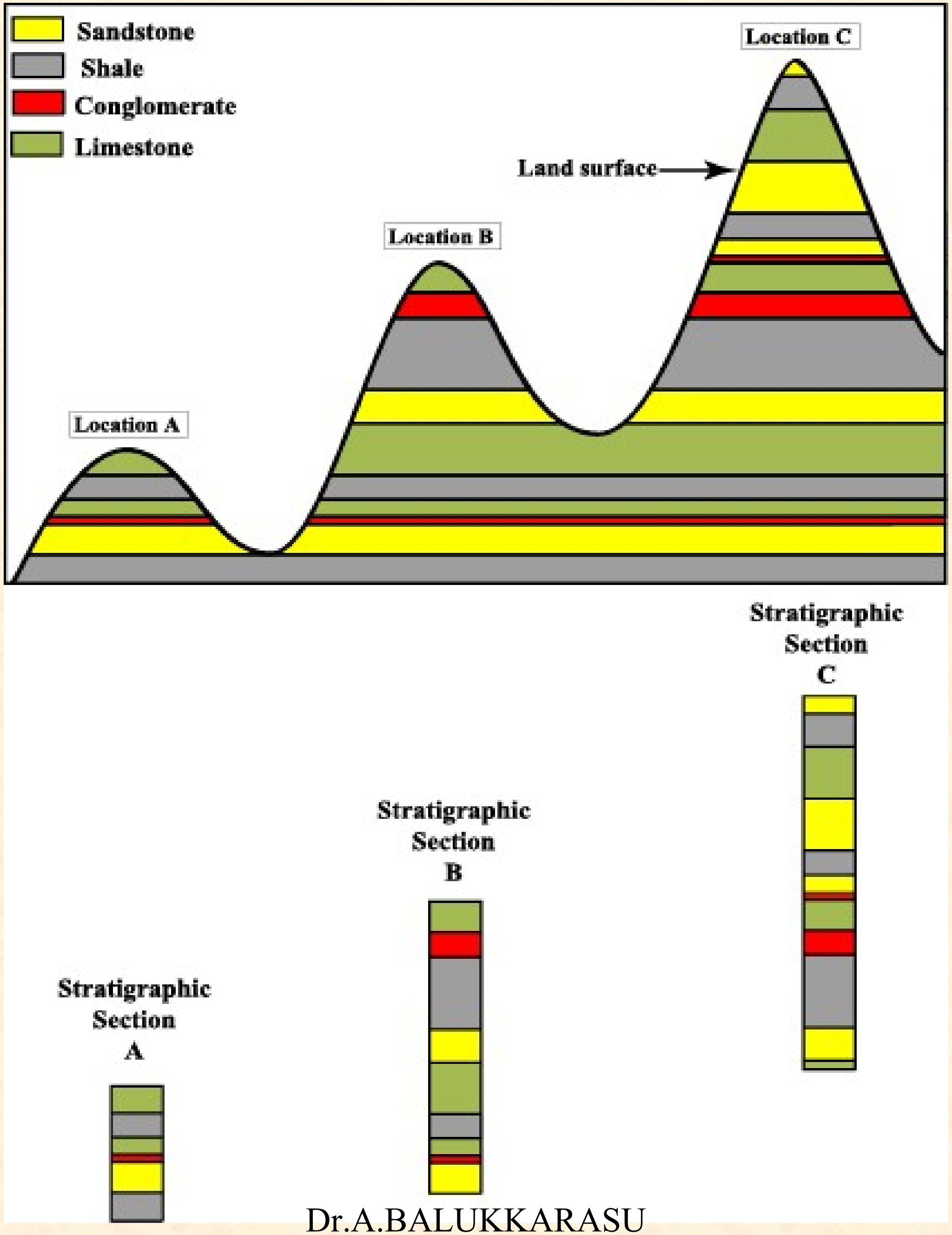
Stratigraphic section: a vertical column describing the sequence of rocks observed at a location.






Sandstone
Shale
Conglomerate
Limestone
Location C
Land surface
Location B
Location A


Stratigraphic Section B
Stratigraphic Section A



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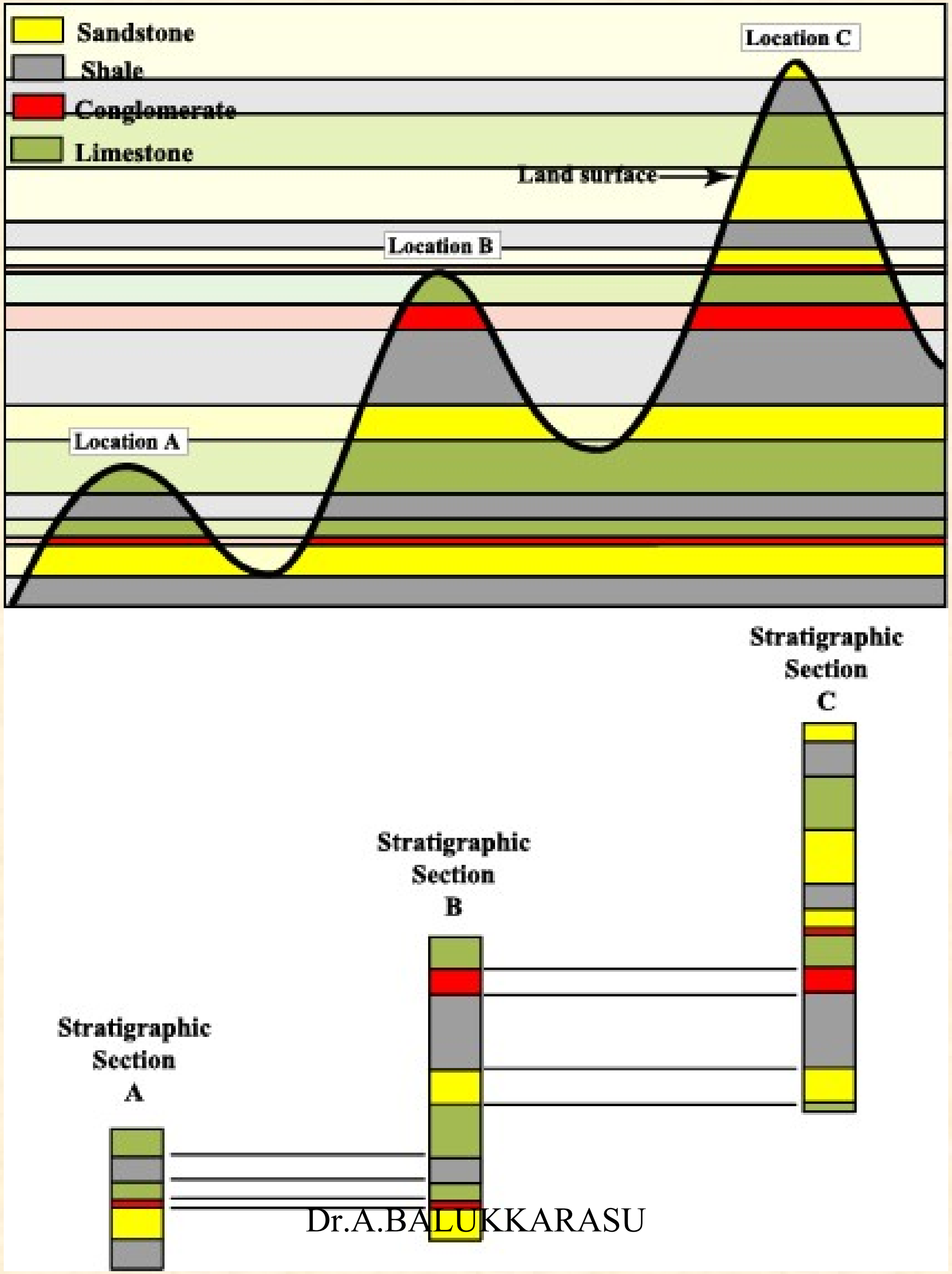

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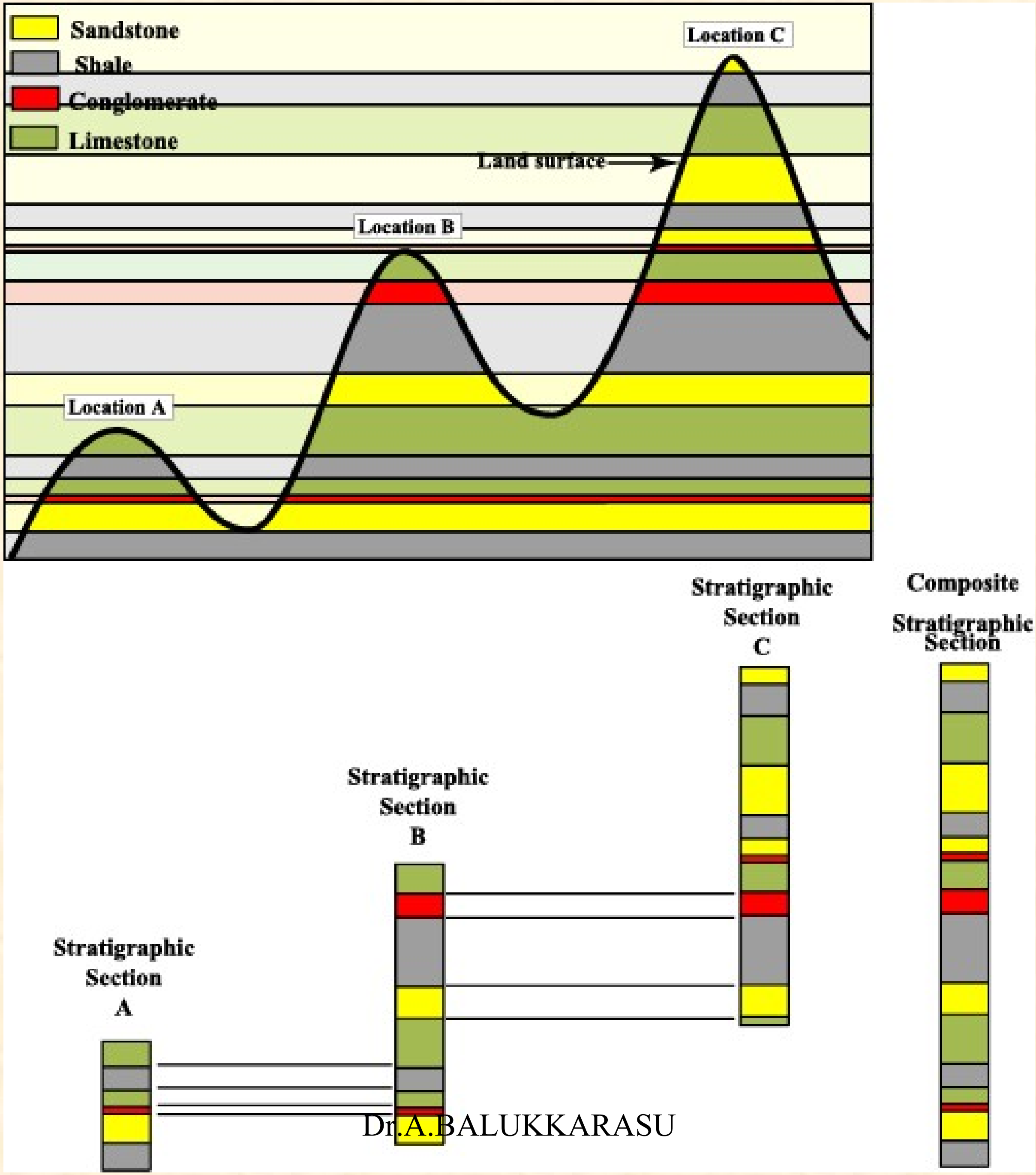

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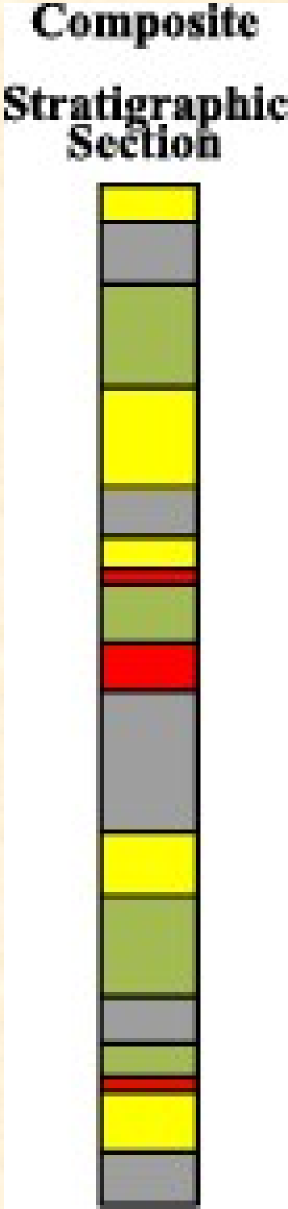
Composite stratigraphic section: a vertical column describing the sequence of rocks that are correlated from two or more locations.

Stratigraphic sections not only show the sequence of rocks but they also show the relative age of rocks (Principle of Superposition).

Problem: rock lithology does not necessarily correlate if the rocks are not infinitely continuous laterally!

Correlation between regions and, particularly continents is virtually impossible on the basis of lithology alone.



Fossils and geologic time

Fossils: the remains of once-living organisms.

Make up a common component of sedimentary rock.

Organisms evolved over time, therefore, the span of time represented by a given fossil is limited.

The sequence of changing fossils reflects evolution over time; the position of a fossil in the sequence reflects its age relative to other fossils/organisms.

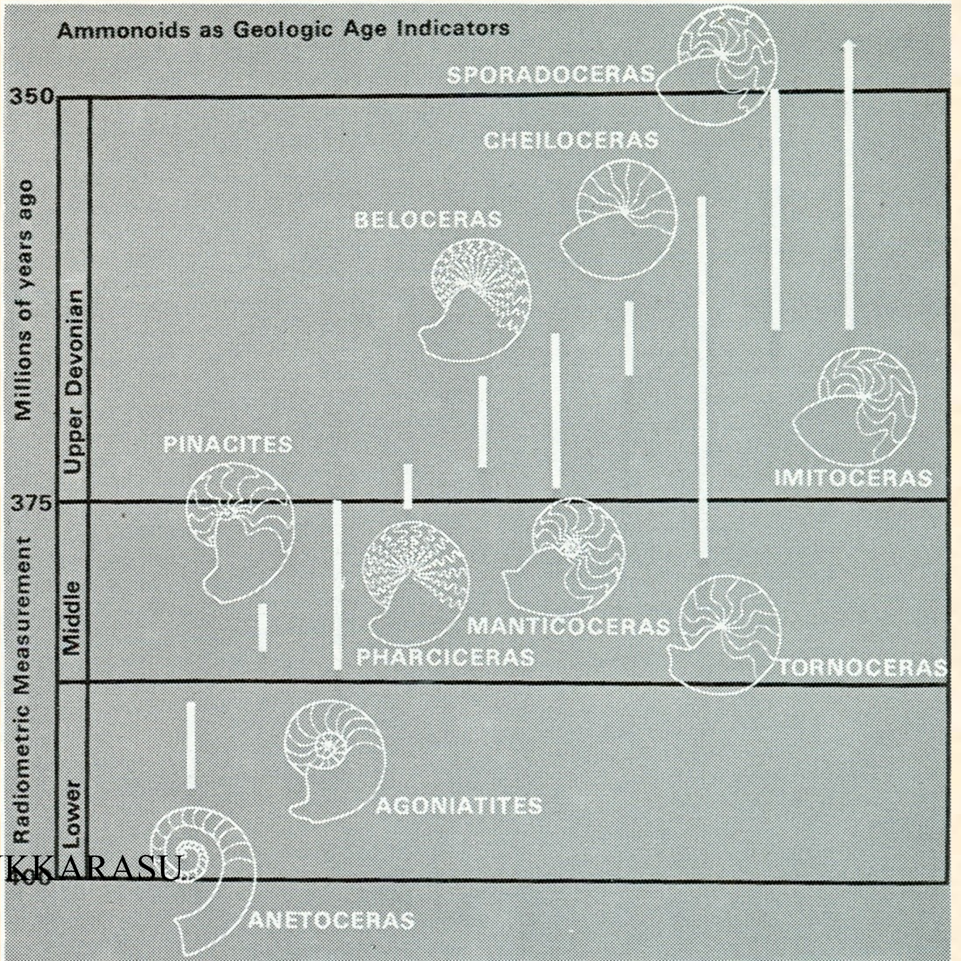
The relative age of a fossil is also the relative age of the rock in which it is preserved.

The fossil was deposited with the sediment at or near the time that the organism was living.

Fossils provide a means of determining the relative age of rocks.

The extent of a fossil in a stratigraphic section represents the range of time that individuals of that organism were present on Earth.

Fossils provide a means of correlating rocks in terms of their age equivalence, world-wide.



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Index Fossil: a fossil that is particularly useful in correlating rocks over wide geographic areas.

Characteristics:

Had a wide geographic extent during life.

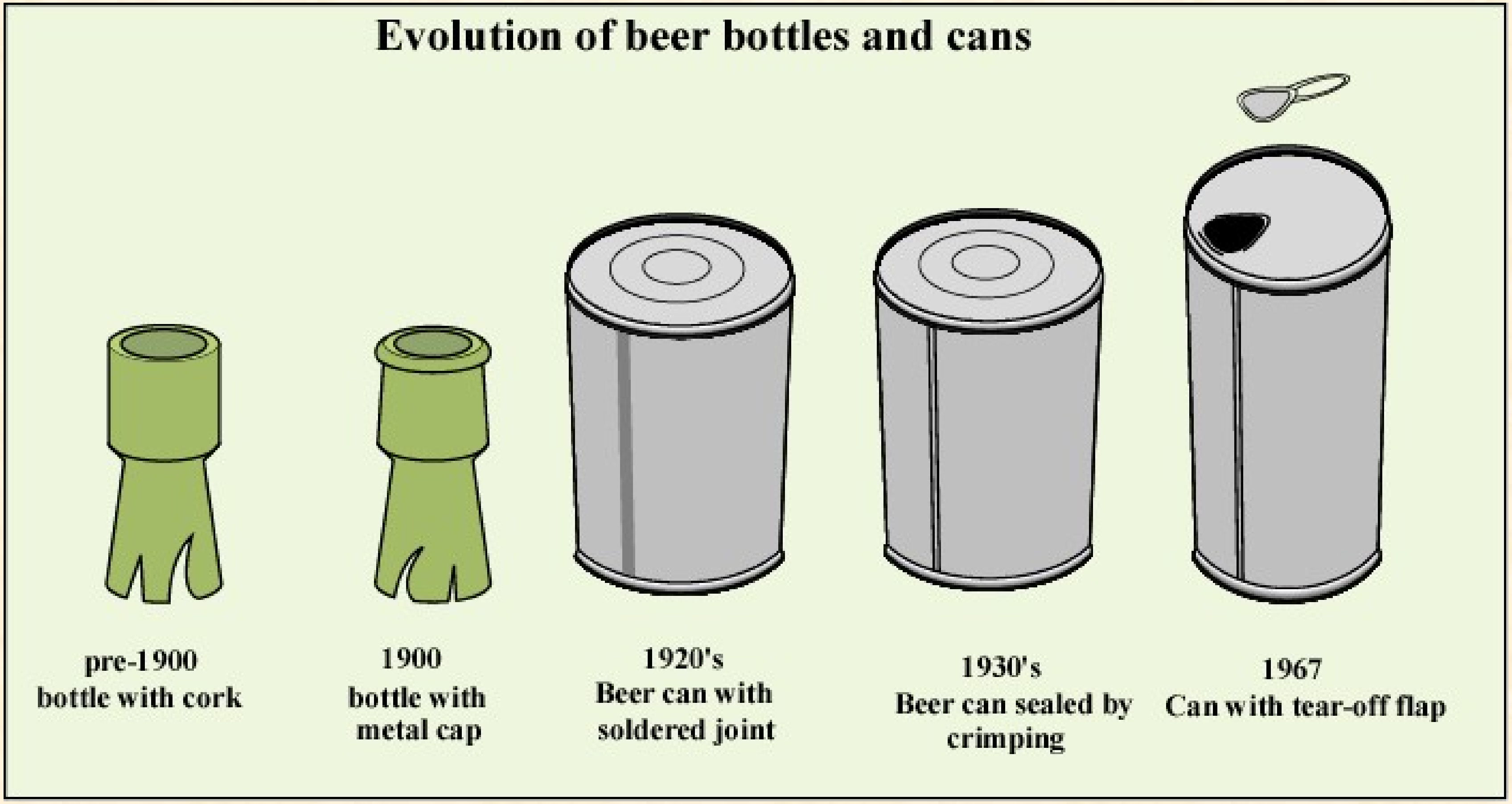
Individuals were abundant.

Had preservable hard parts.

Existed for a geologically short period of time.

Index fossils provide a means of correlating rocks world-wide and allow for the development of a global composite stratigraphic sequence.

The Beer Container Time Scale



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Individuals were abundant.

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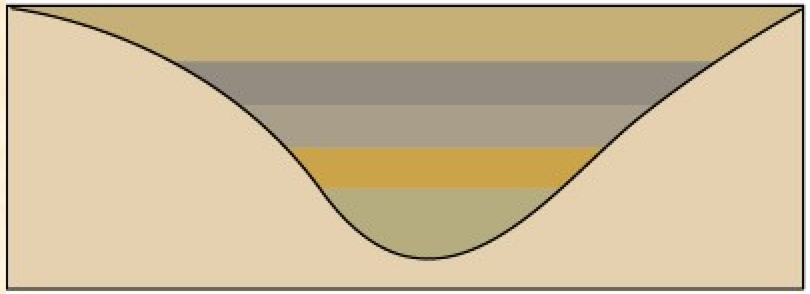
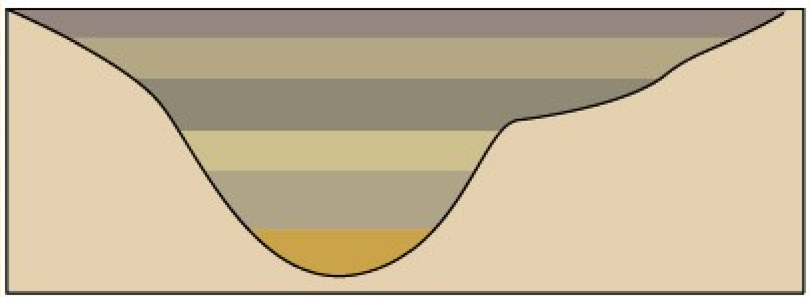
Existed for a geologically short period of time.

Dump Stratigraphy

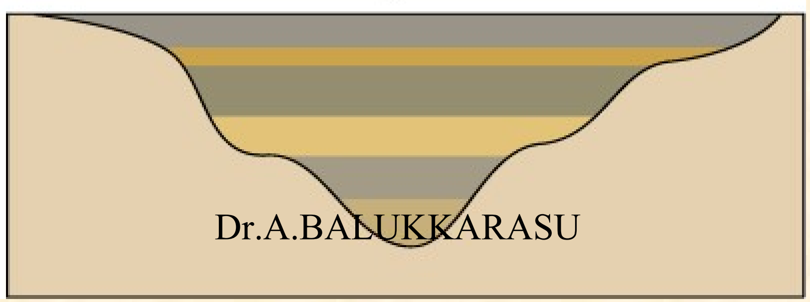
Dump site 1.
Brandon, Manitoba



Dump site 2.
Buffalo, New York

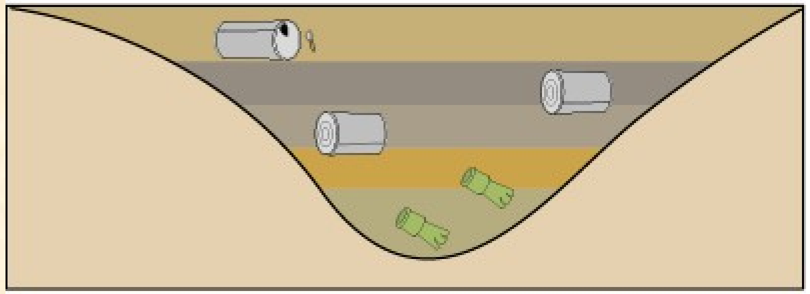


Dump site 3.
Welland, Ontario

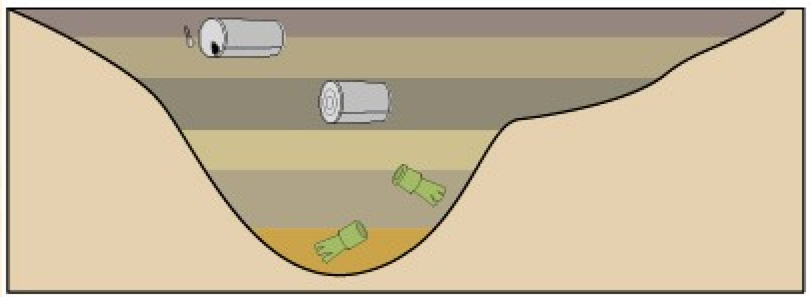


Dump Stratigraphy

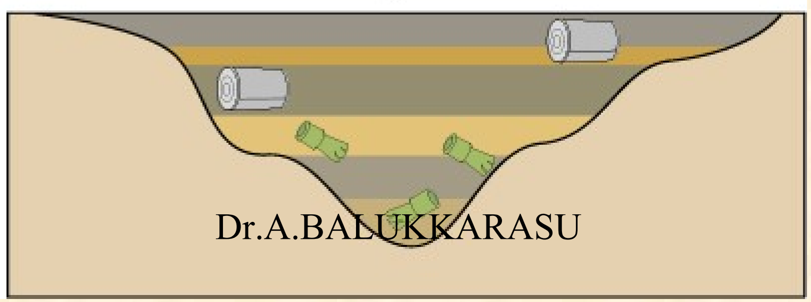
Dump site 1.
Brandon, Manitoba

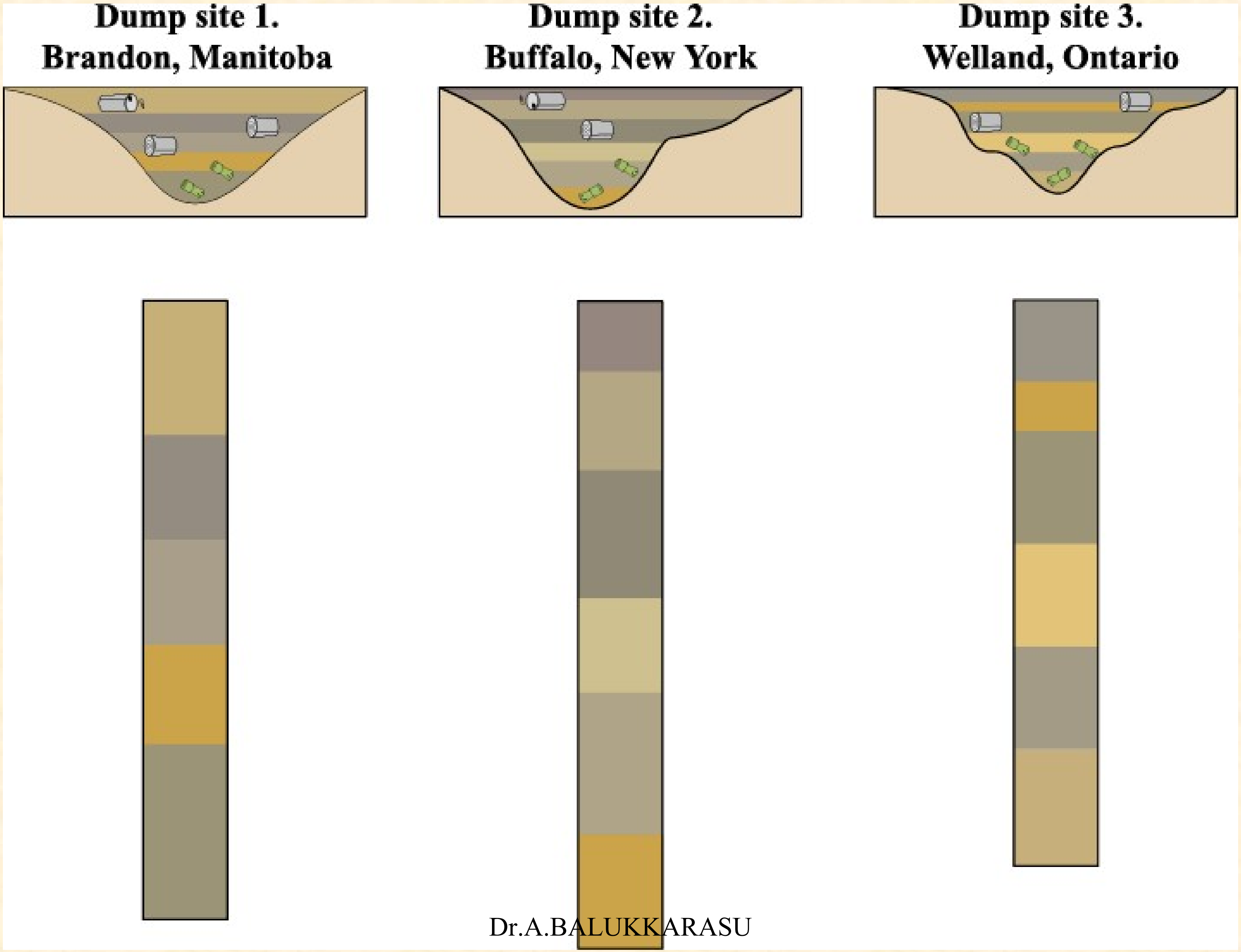


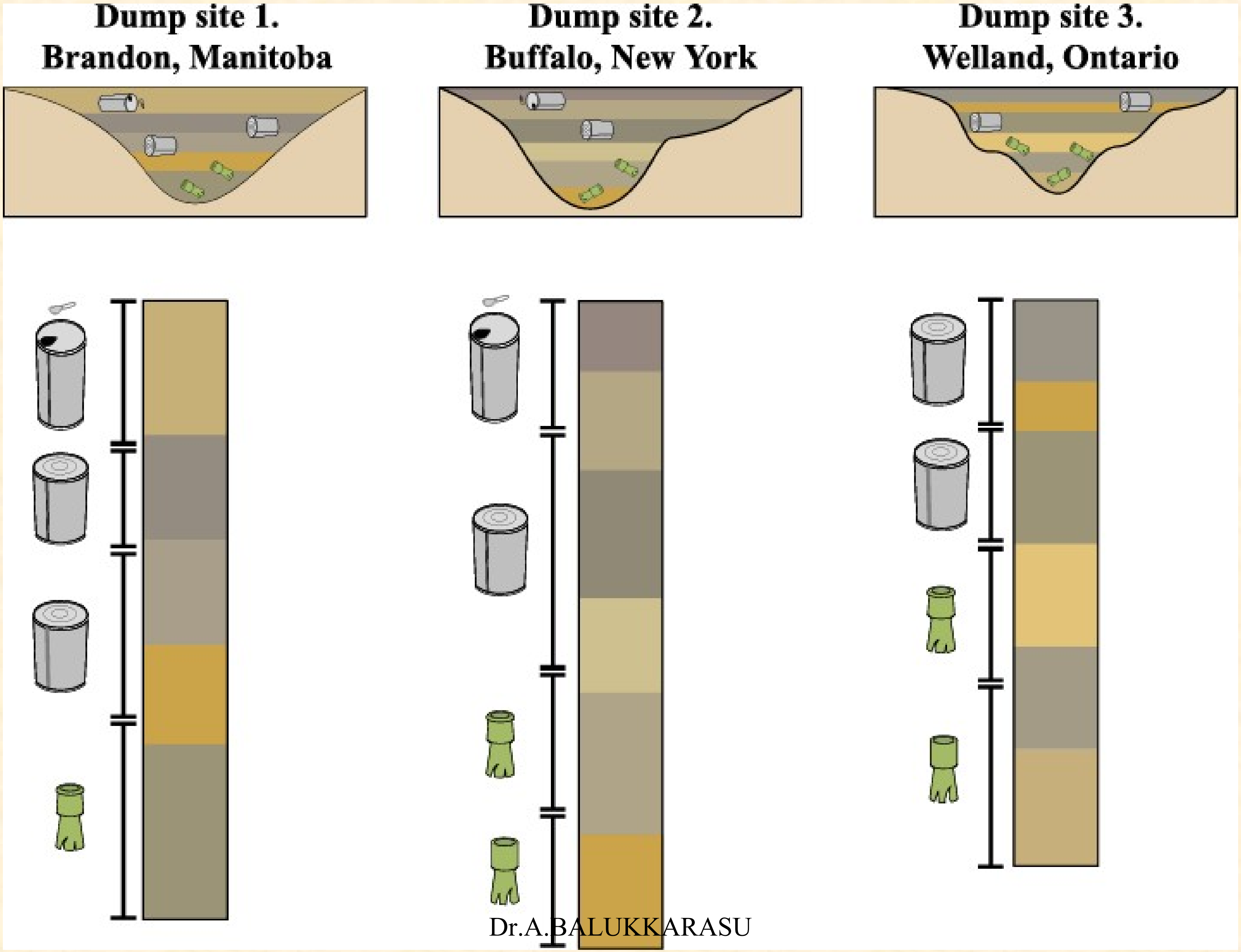
Dump site 2.
Buffalo, New York



Dump site 3.
Welland, Ontario




Dump site 1.
Brandon, Manitoba
Dump site 2.
Buffalo, New York
Dump site 3.
Welland, Ontario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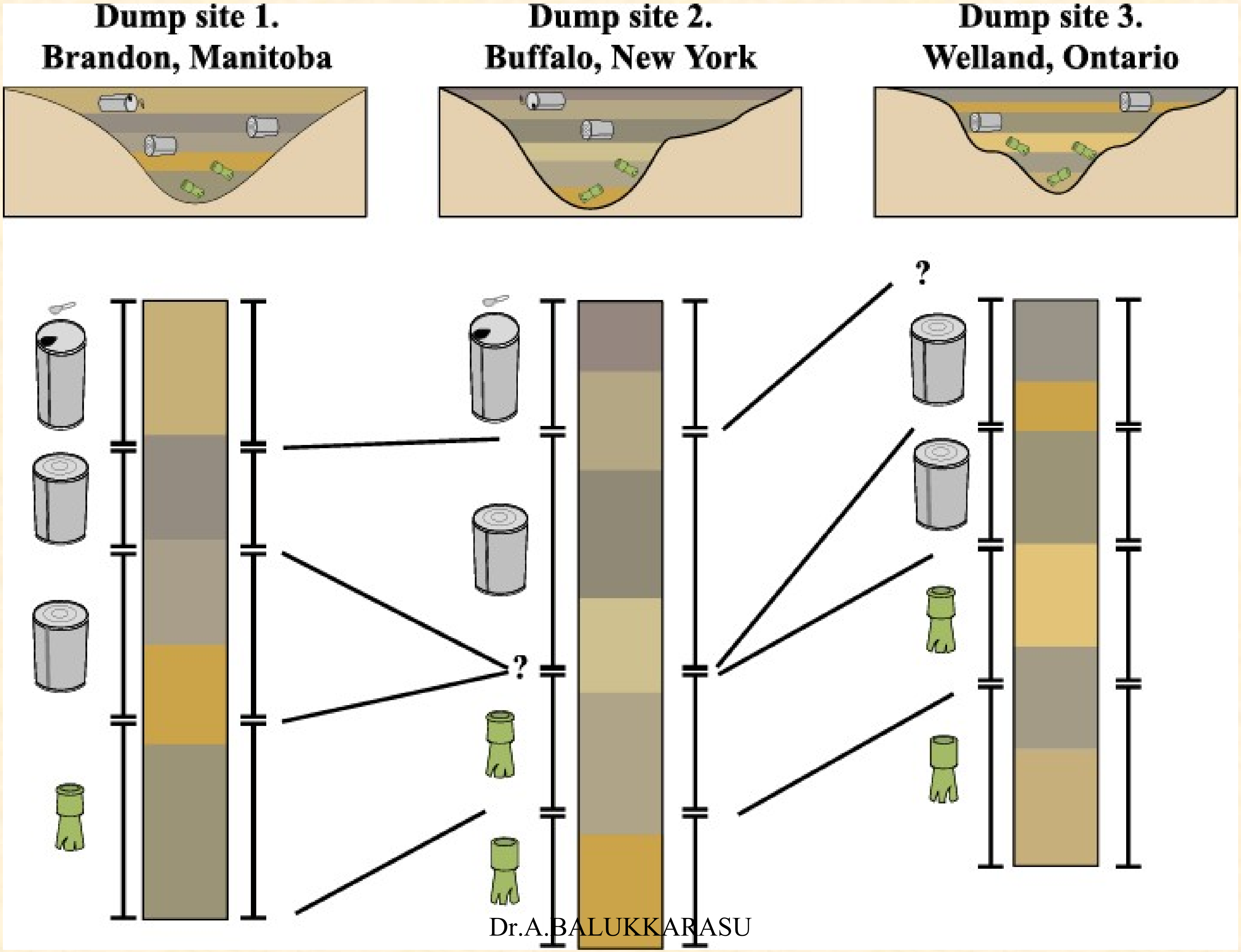
Dump site 2.
Buffalo, New York
Dump site 3.
Welland, Ontario



Dump site 1.
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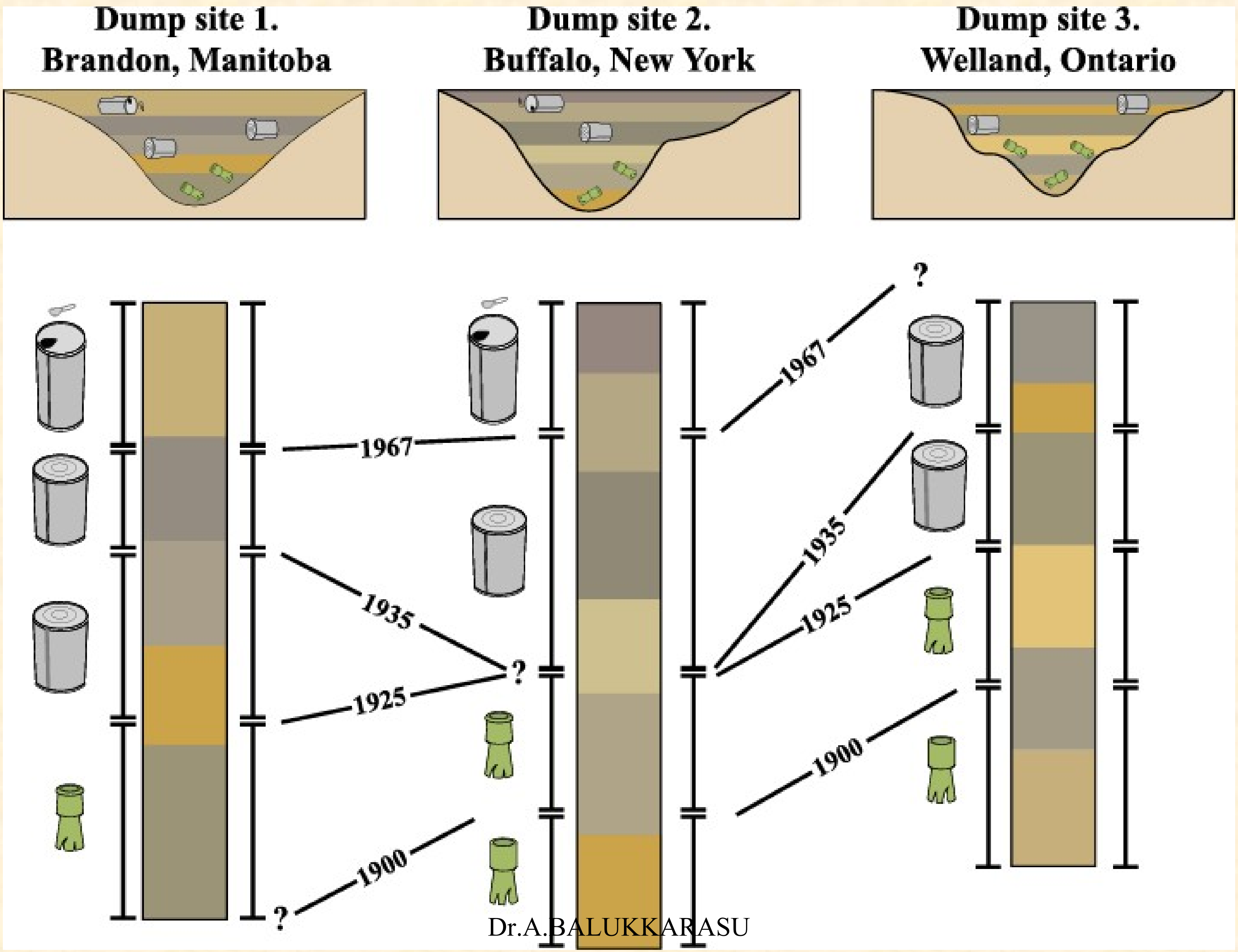
Dump site 2.
Buffalo, New York
Dump site 3.
Welland, Ontario
?
?



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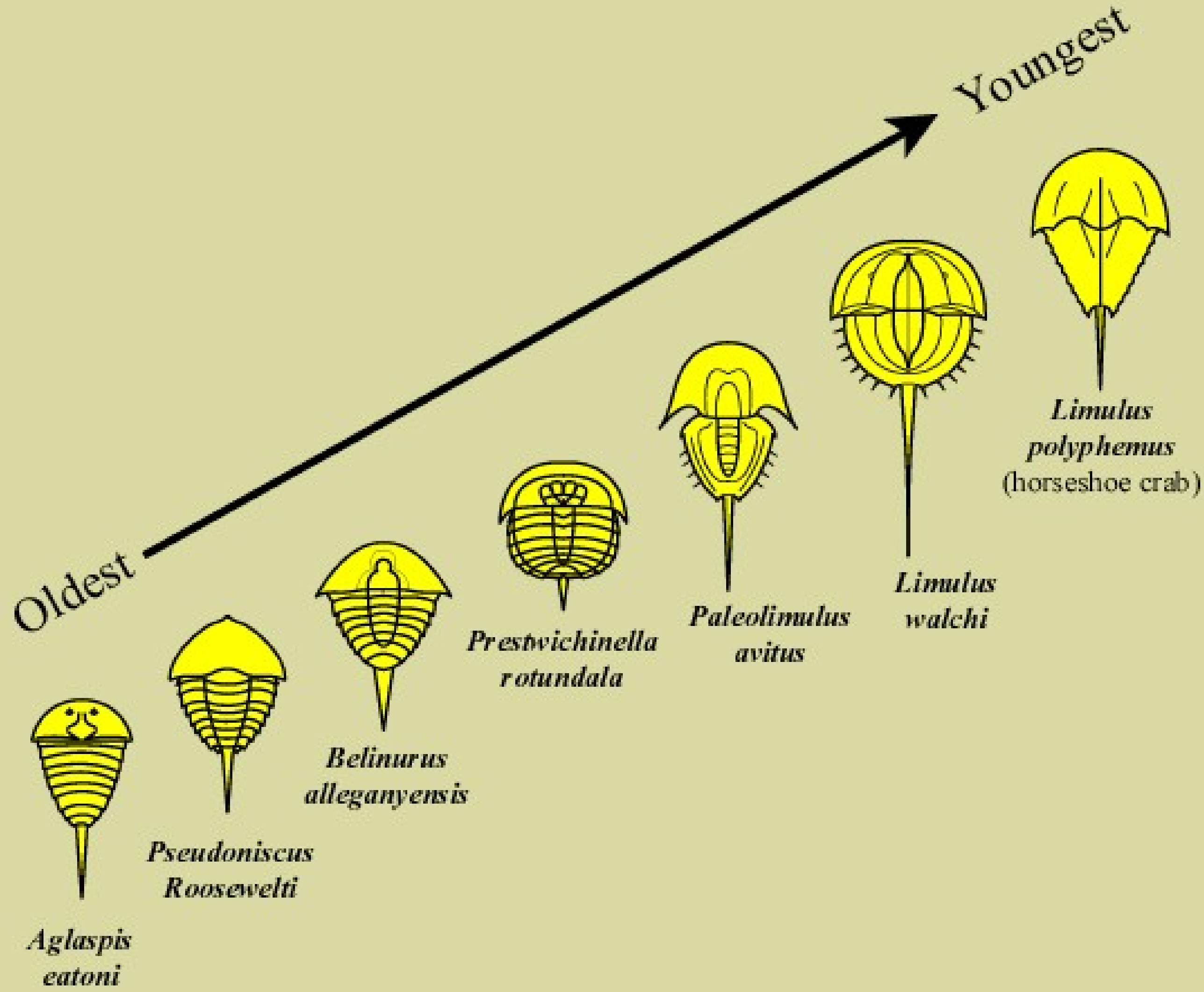
Morphological evolution of Arthropods



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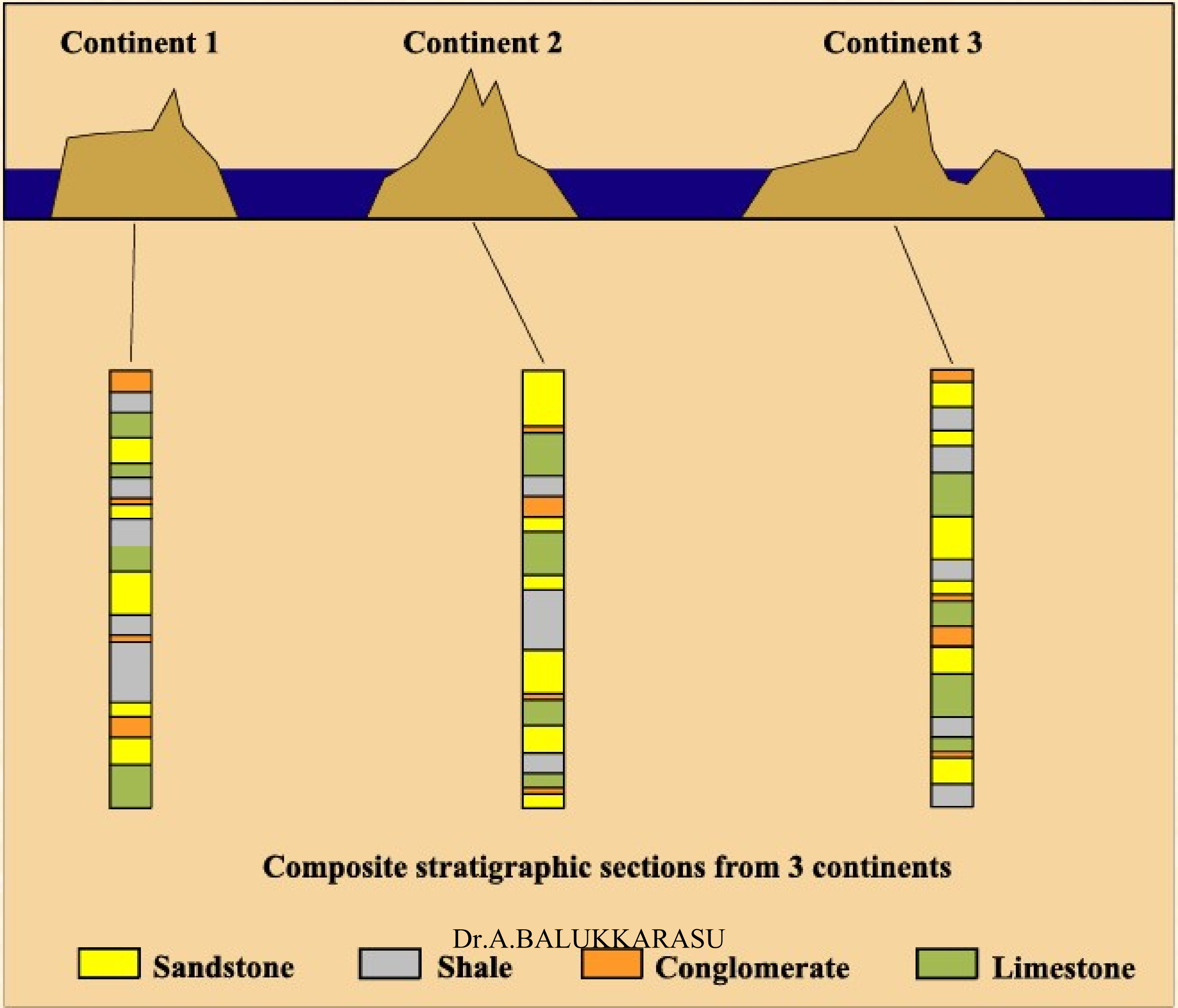

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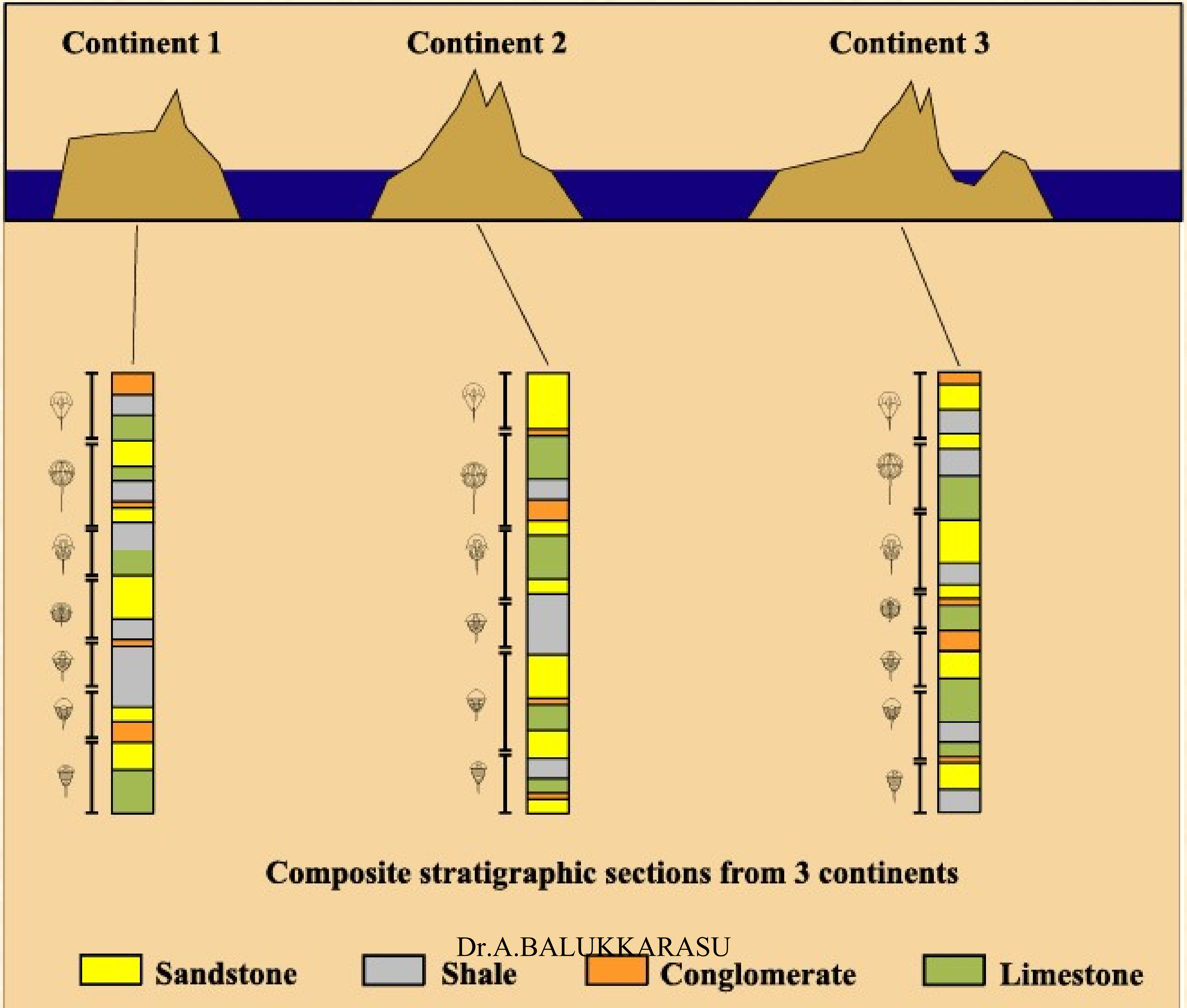

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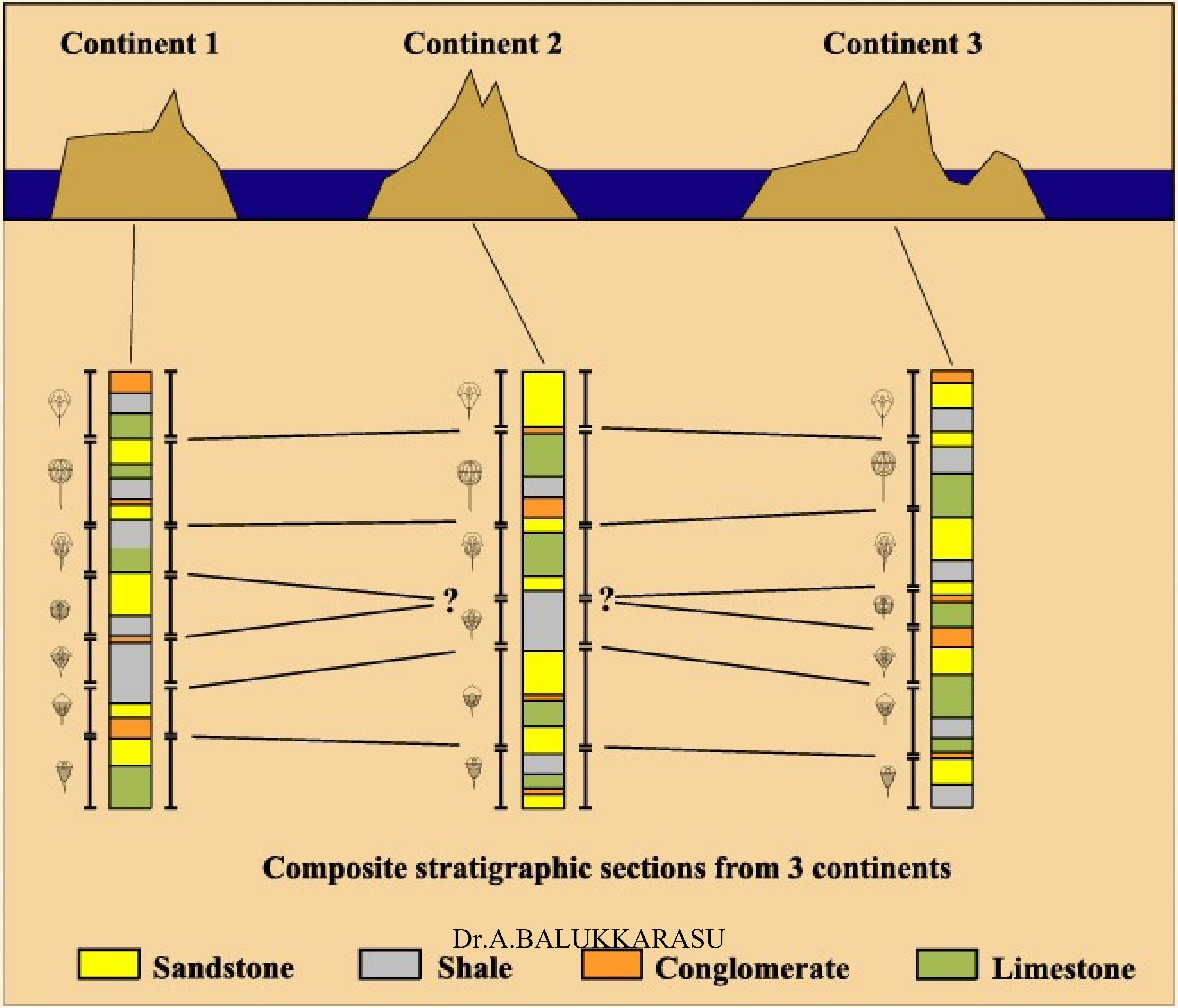

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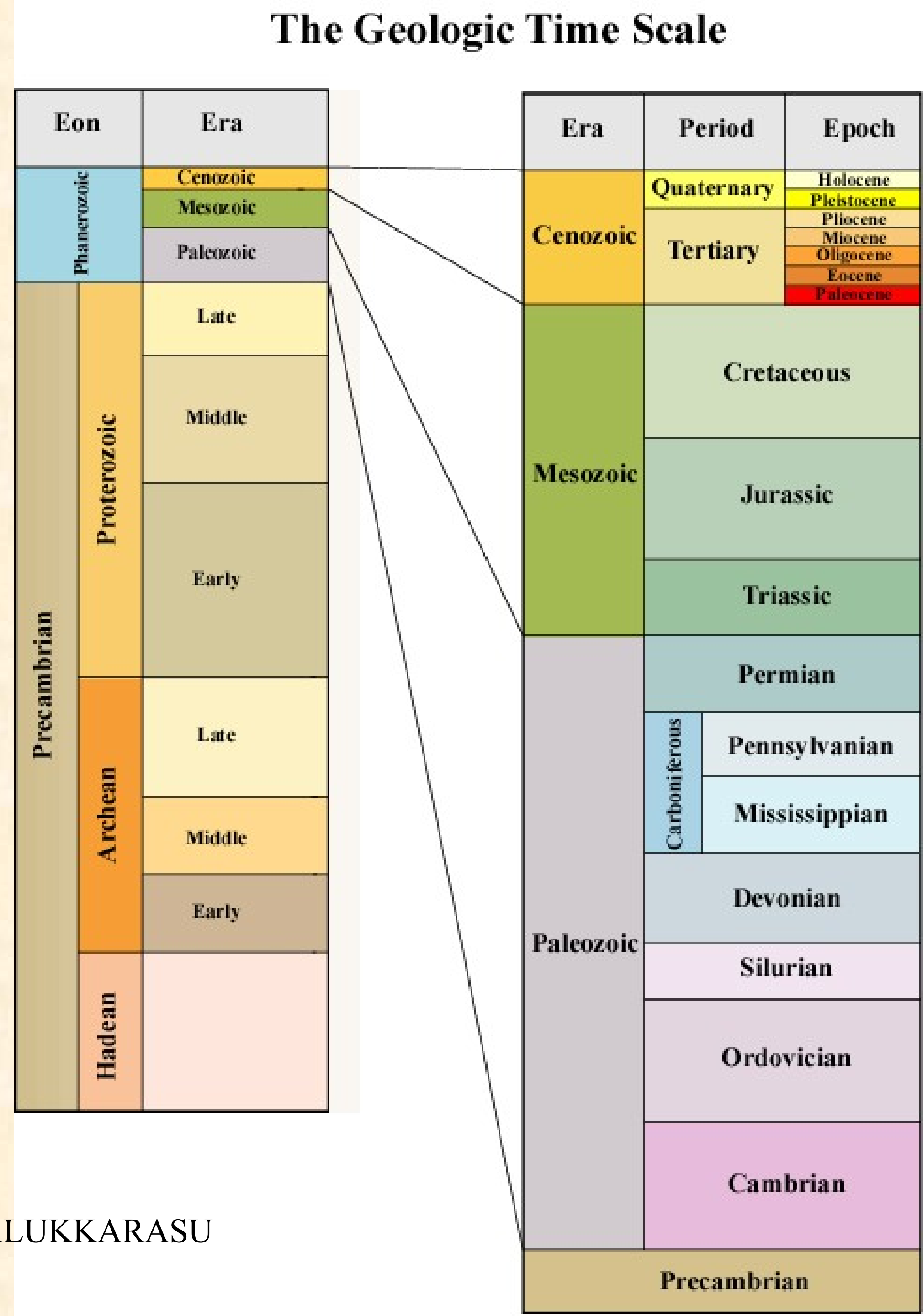
The Geologic Time Scale

Developed by the process of correlation, using fossils, of the sequence of rocks world-wide.

In order of decreasing duration:

Eons	**e.g., Phanerozoic, time of abundant life.**
Eras	**e.g., Cenozoic, most recent life.**
Periods	**e.g., Cretaceous, age of dinosaurs.**
Epochs	**e.g., Pleistocene, most recent age of continental glaciation.**

The names of the periods reflect either a common rock type or the location where the rocks were first recognized.



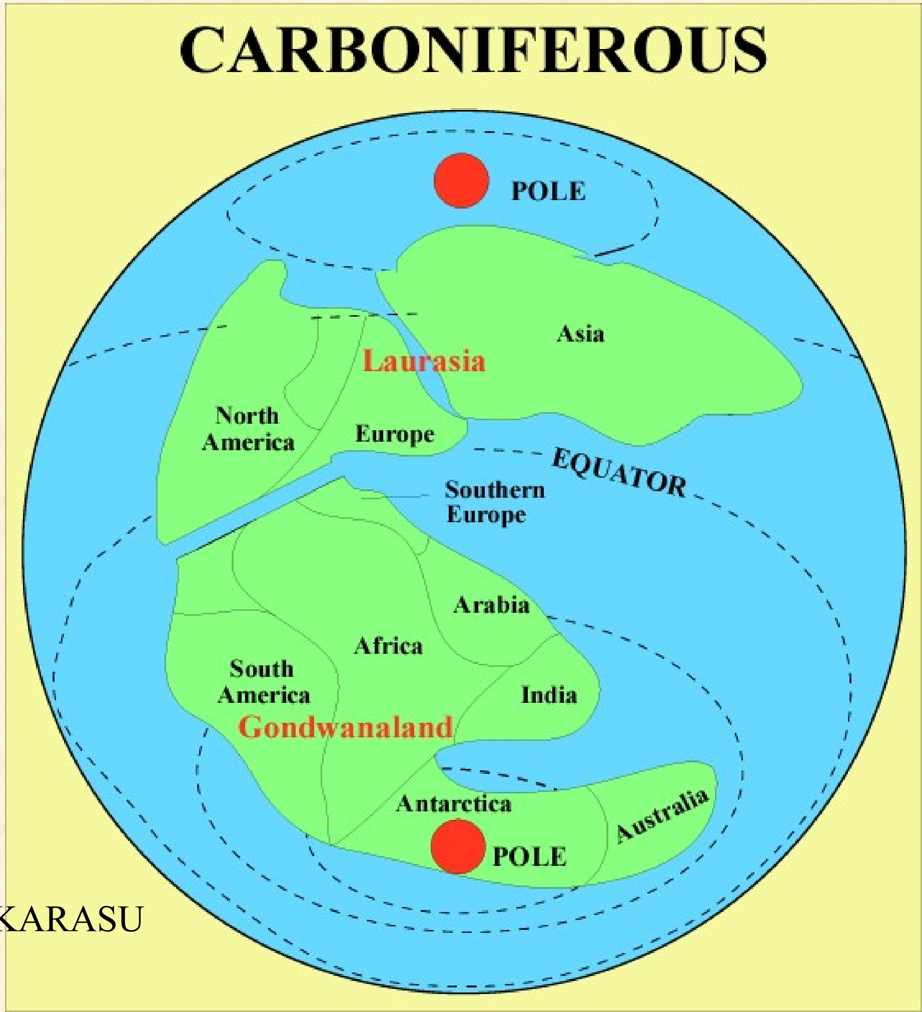
Cretaceous**: in Britain widespread chalks are preserved (Latin for chalk is "creta").**

Chalk is a deep water carbonate sediment.

A widespread deposit of Cretaceous age because sea level was high during that period.

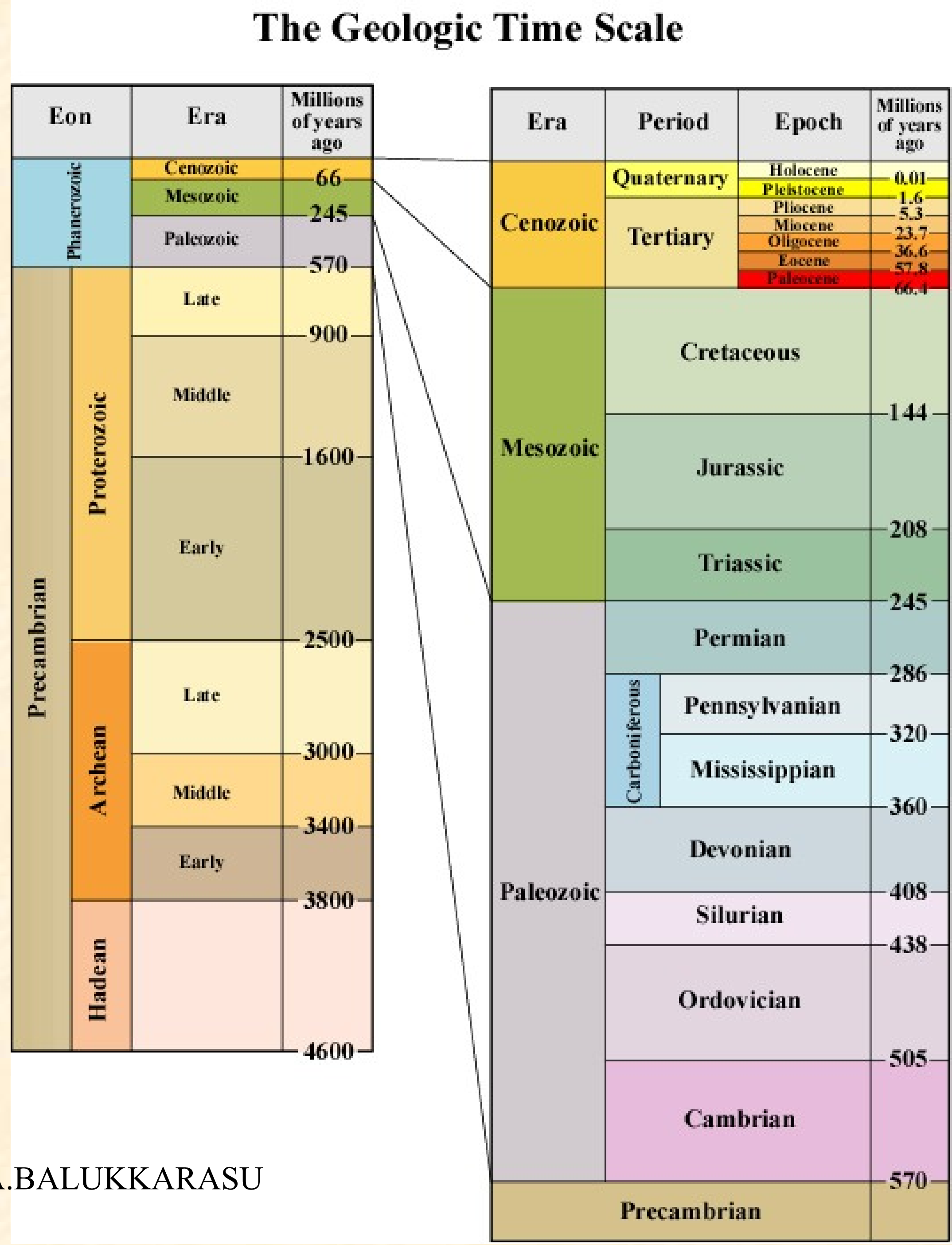
Carboniferous: named for widespread coal deposits associated with rocks of this age in North America and Britain.

North America and Europe were located near the equator and experienced tropical conditions during the Carboniferous.



Jurassic: named for the Jura Mountains (between France and Switzerland) where rocks of this age were first studied.

The modern geologic time scale defines subdivision boundaries with absolute ages based on radiometric dating of rocks.

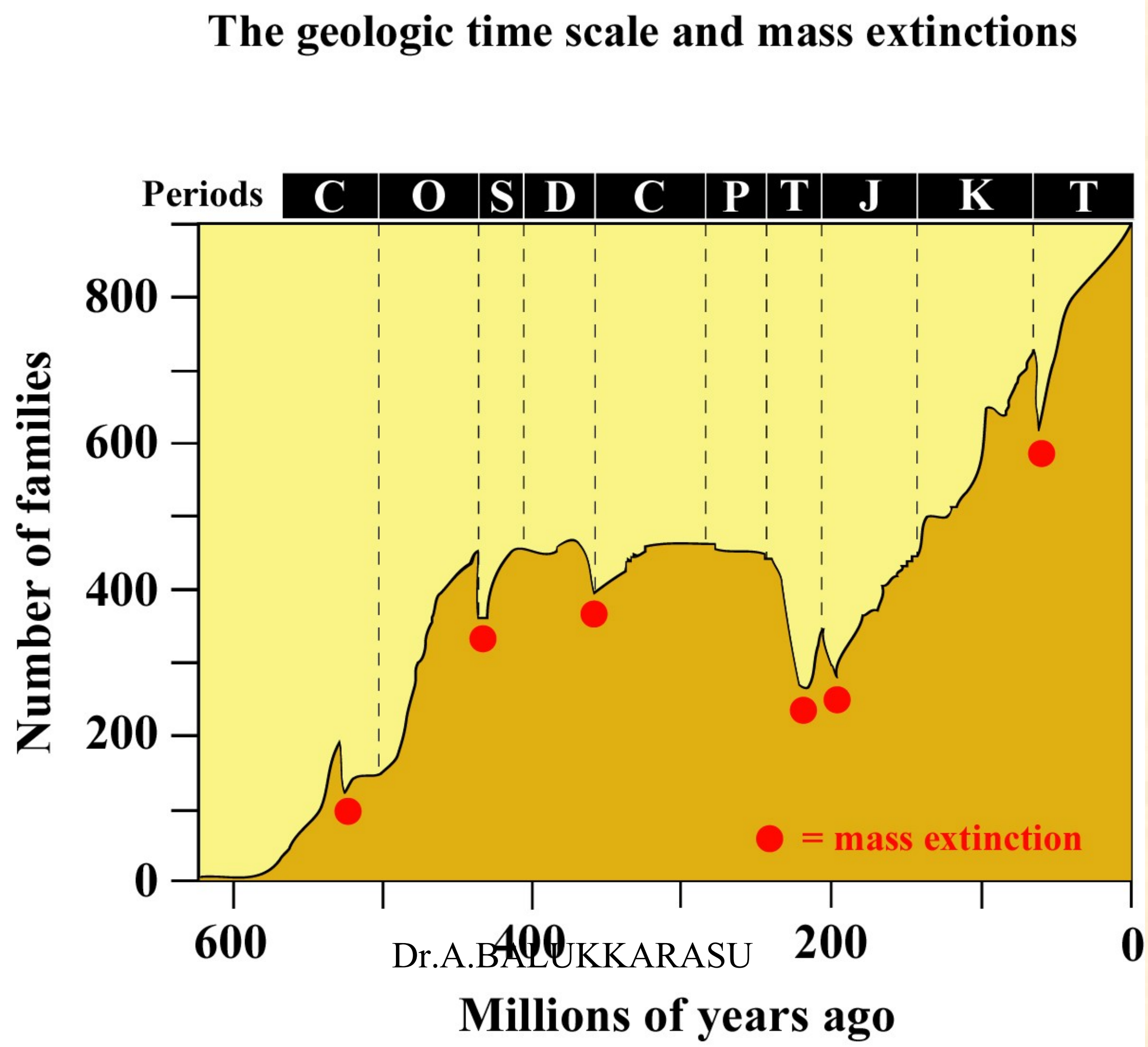


Each subdivision is characterized by fossils and many differ in terms of global events.

Era	Period		Epoch	Millions of years ago	Plants and animals
Cenozoic	Quaternary		Holocene	0.01	Humans develop
			Pleistocene	1.6	
	Tertiary		Pliocene	5.3	Mammals dominate
			Miocene	23.7	
			Oligocene	36.6	
			Eocene	57.8	
			Paleocene	66.4	Extinction of the dinosaurs
Mesozoic	Cretaceous			144	First flowering plants
	Jurassic			208	First birds
	Triassic			245	Dinosaurs dominate
Paleozoic	Permian			286	Extinction of trilobites and many other marine species
	Carboniferous	Pennsylvanian		320	First reptiles
		Mississippian		360	Coal swamps abundant Amphibians are abundant
	Devonian			408	First insects Fishes dominate
	Silurian			438	First land plants
	Ordovician			505	First fishes
	Cambrian			570	Trilobites dominate First shelled organisms
Precambrian				4600	First multi-celled organisms First single-cell organisms Origin of the Earth

Many Period boundaries fall on mass extinctions.

This reflects the close relationship between the divisions of the time scale and the fossil record, particularly the fact that extinctions marked points in time when life on Earth changed dramatically.



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