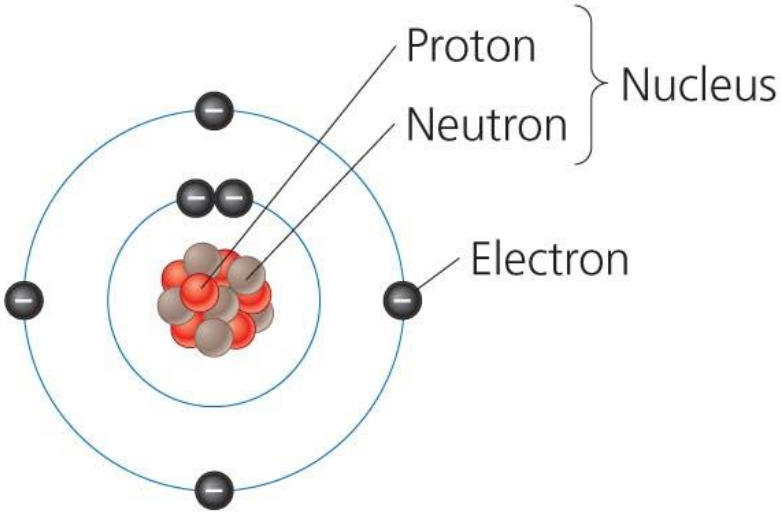
Earth's Physical Systems: Matter, Energy and Geology

This lecture will help you understand:

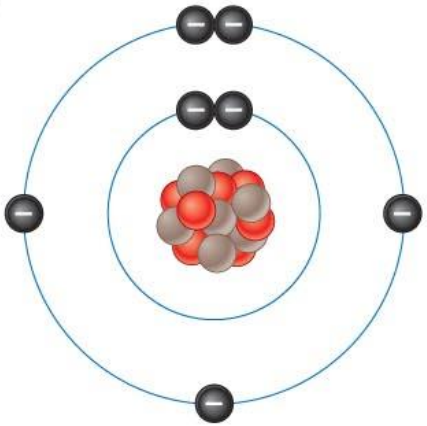
- The fundamentals of matter and chemistry
- Energy and energy flow
- Photosynthesis, respiration, and chemosynthesis
- Plate tectonics and the rock cycle
- Geologic hazards and ways to mitigate them

TABLE 2.1 Earth's Most Abundant Chemical Elements, by Mass

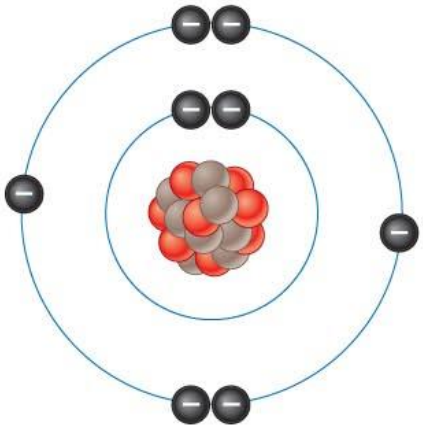
Earth's crust		Oceans		Air		Organisms	
Oxygen (O)	49.5%	Oxygen (O)	88.3%	Nitrogen (N)	78.1%	Oxygen (O)	65.0%
Silicon (Si)	25.7%	Hydrogen (H)	11.0%	Oxygen (O)	21.0%	Carbon (C)	18.5%
Aluminum (Al)	7.4%	Chlorine (Cl)	1.9%	Argon (Ar)	0.9%	Hydrogen (H)	9.5%
Iron (Fe)	4.7%	Sodium (Na)	1.1%	Other	<0.1%	Nitrogen (N)	3.3%
Calcium (Ca)	3.6%	Magnesium (Mg)	0.1%			Calcium (Ca)	1.5%
Sodium (Na)	2.8%	Sulfur (S)	0.1%			Phosphorus (P)	1.0%
Potassium (K)	2.6%	Calcium (Ca)	<0.1%			Potassium (K)	0.4%
Magnesium (Mg)	2.1%	Potassium (K)	<0.1%			Sulfur (S)	0.3%
Other	1.6%	Bromine (Br)	<0.1%			Other	0.5%



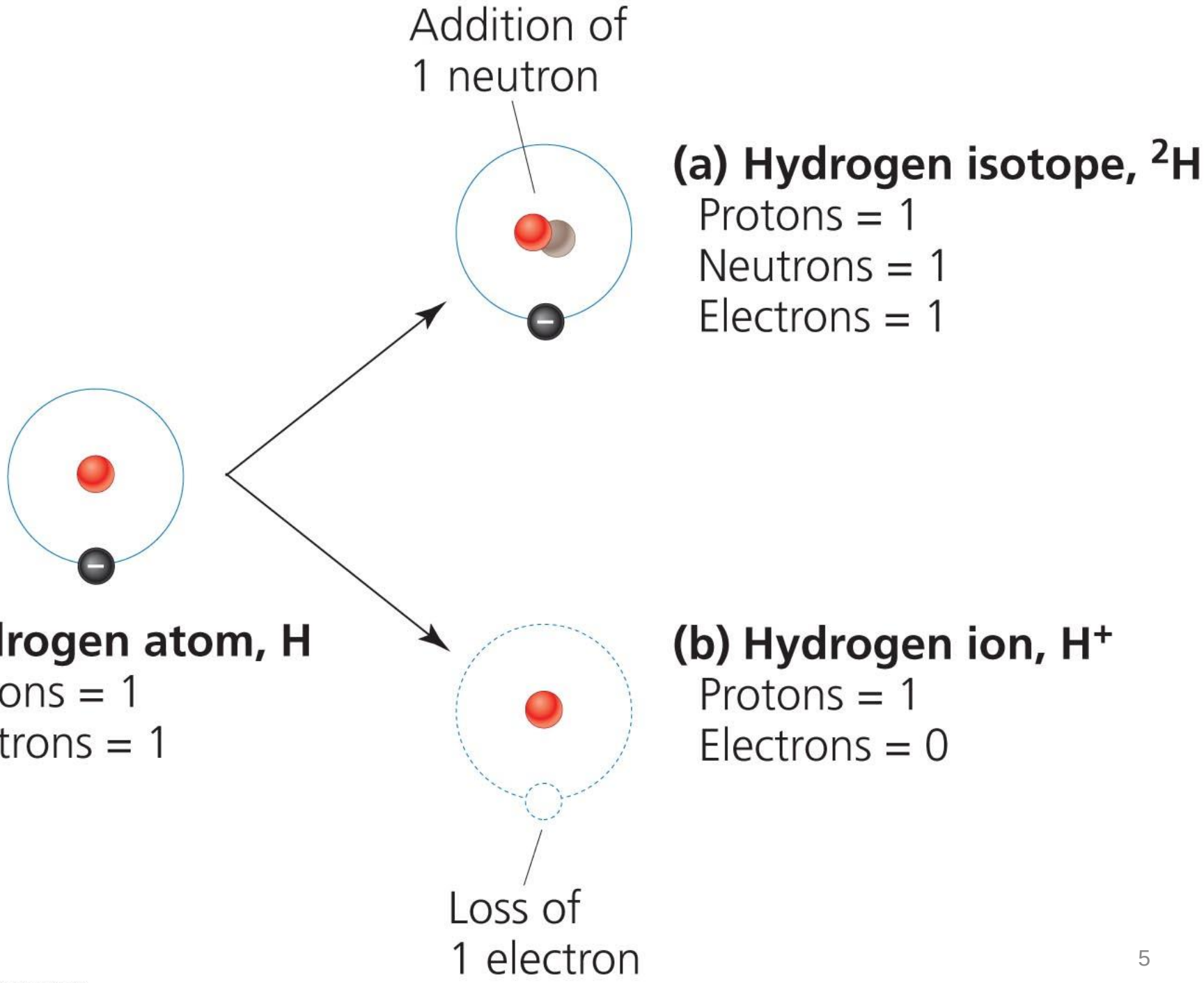
Carbon (C)
Atomic number = 6
Protons = 6
Neutrons = 6
Electrons = 6



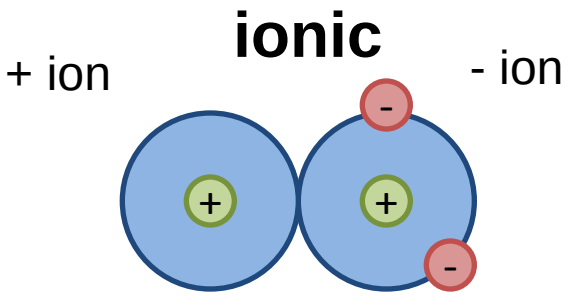
Nitrogen (N)
Atomic number = 7
Protons = 7
Neutrons = 7
Electrons = 7



Oxygen (O)
Atomic number = 8
Protons = 8
Neutrons = 8
Electrons = 8

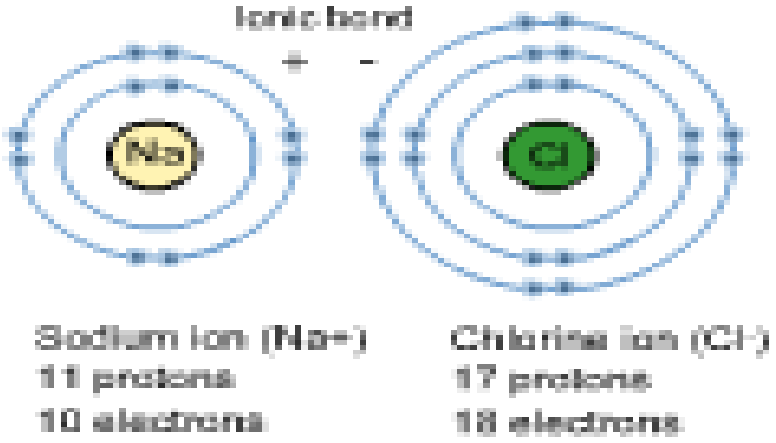


Ionic bonds



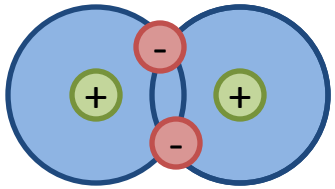
Transfer of electrons

Example: Halite
(sodium chloride)



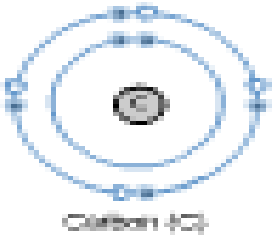
Covalent bonds

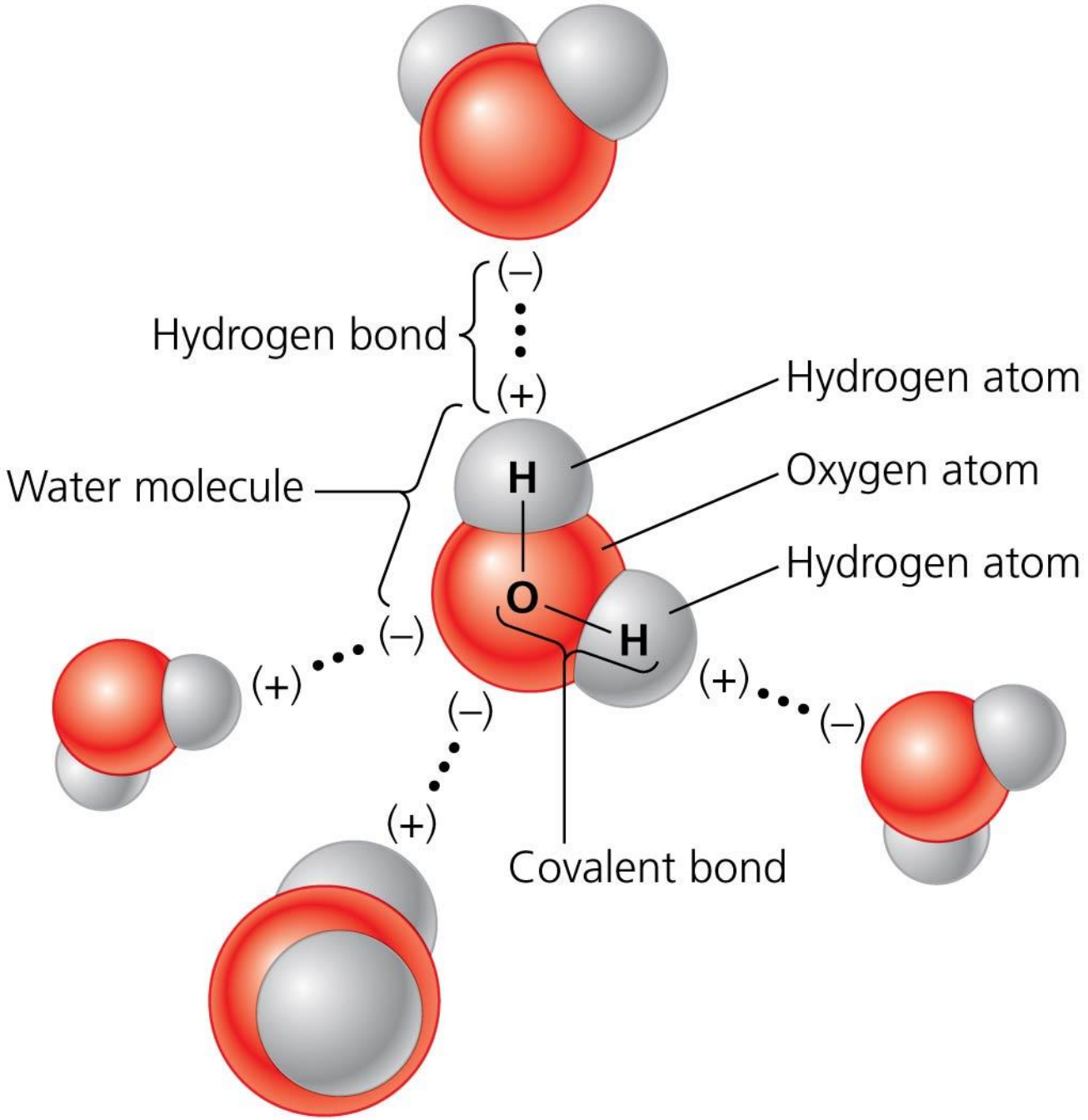
covalent

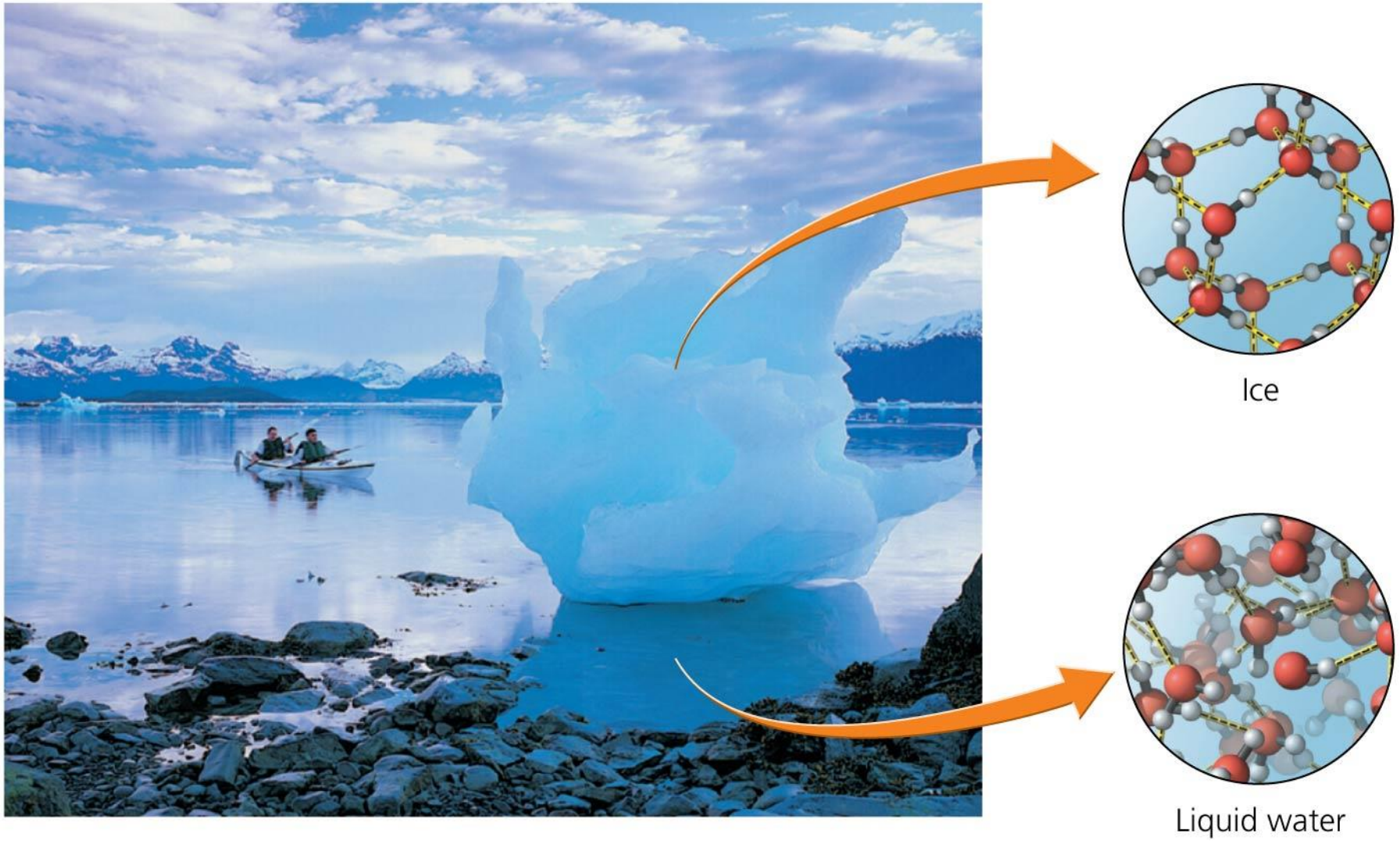


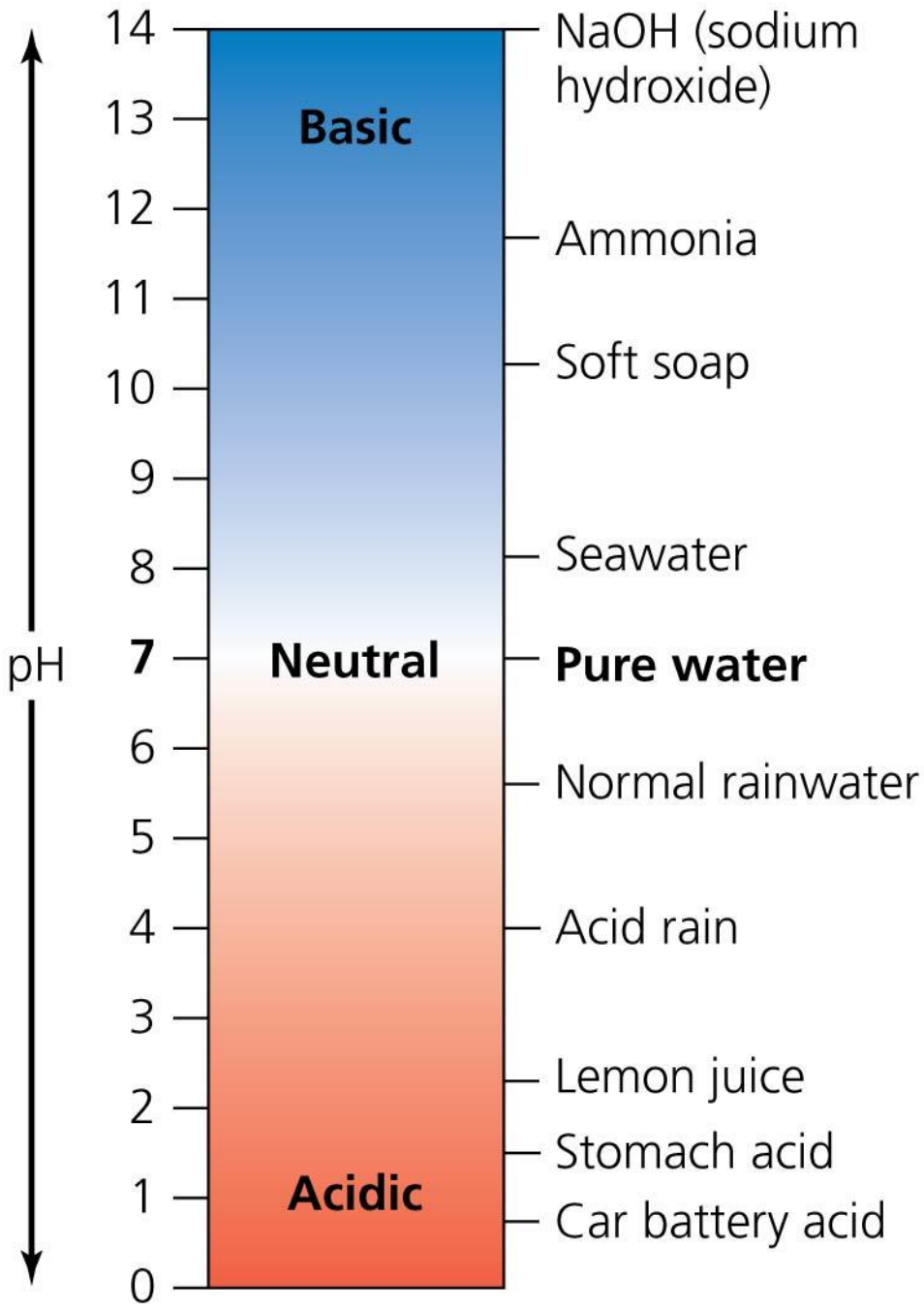
Sharing of electrons

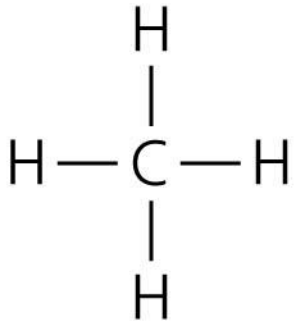
Example: H_2

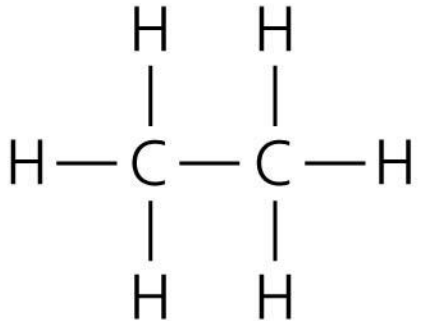


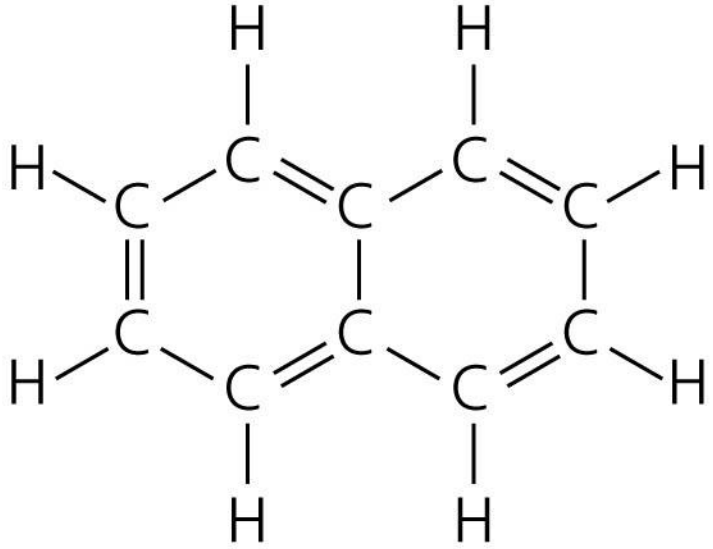

Hydrogen bond
(–)
(+)
Hydrogen atom
Water molecule
H
Oxygen atom
O
Hydrogen atom
H
(–)
(+)
(–)
(+)
(+)
(–)
Covalent bond


Ice
Liquid water


pH
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Basic
Neutral
Acidic
NaOH (sodium hydroxide)
Ammonia
Soft soap
Seawater
Pure water
Normal rainwater
Acid rain
Lemon juice
Stomach acid
Car battery acid



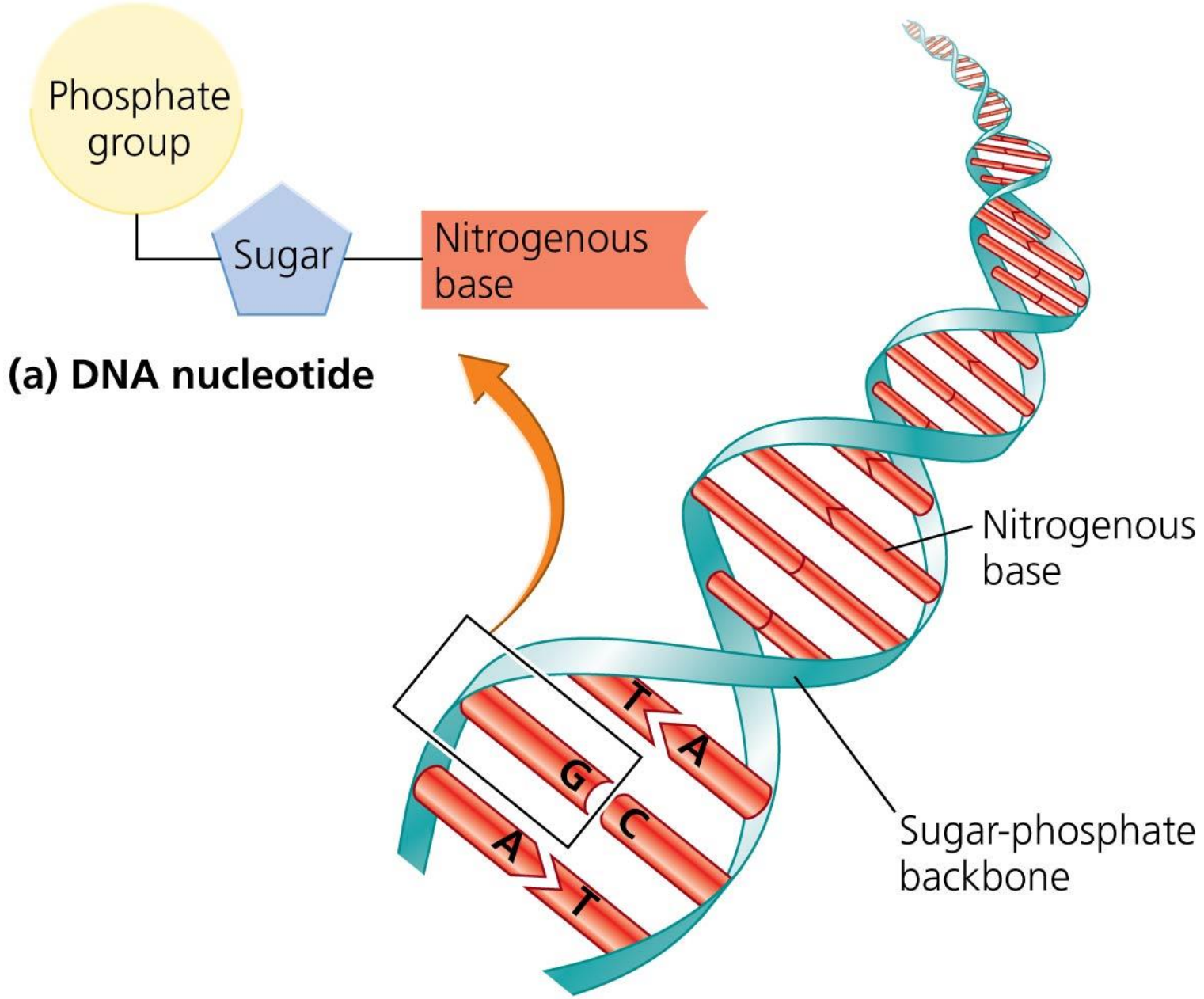


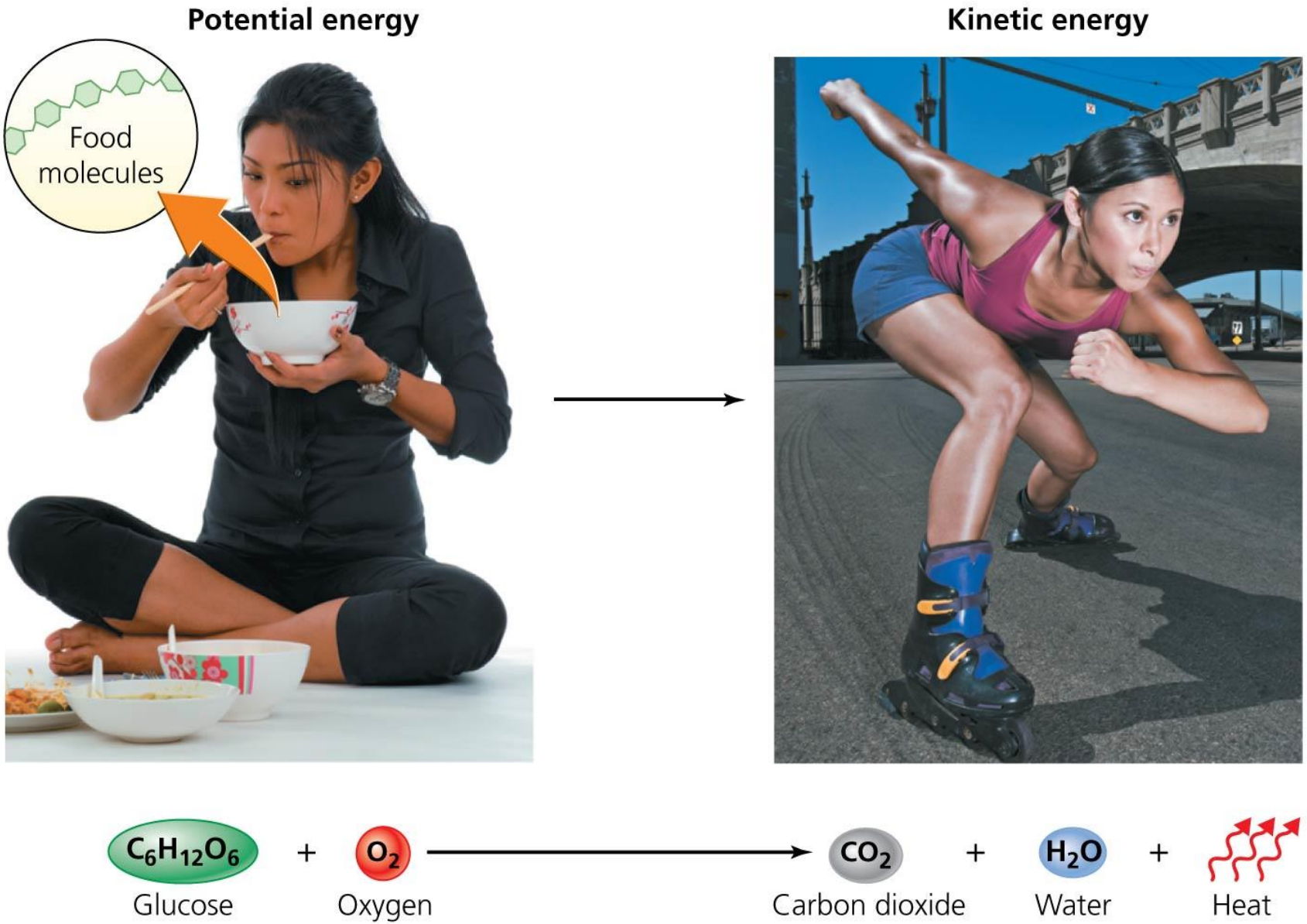


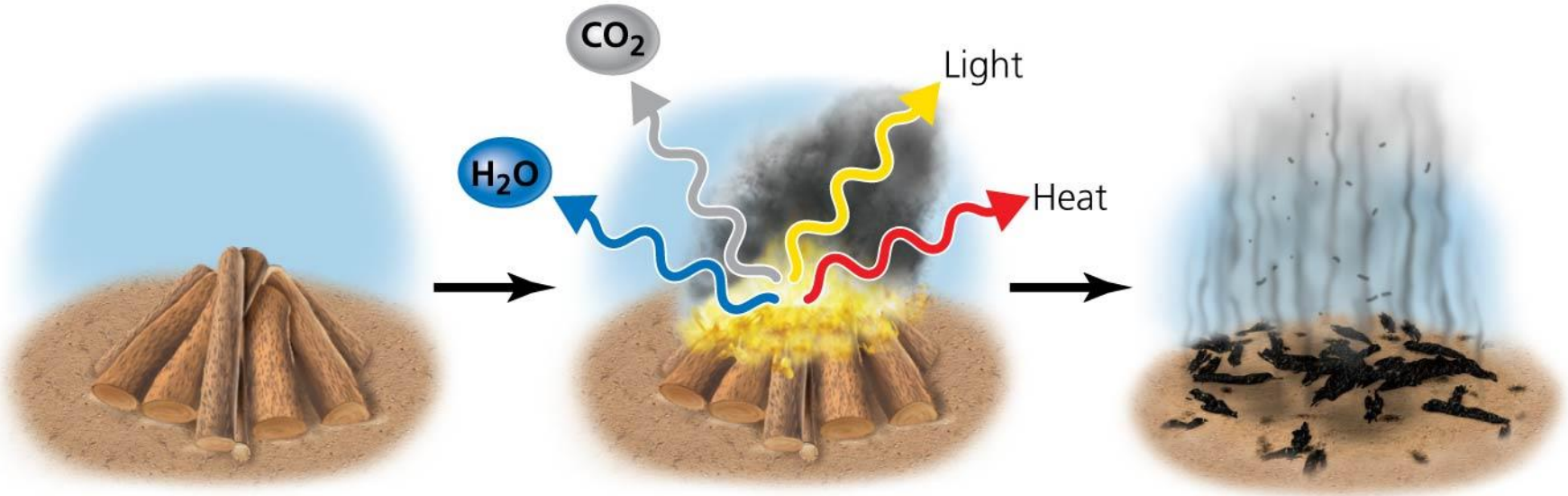
(a) Methane, CH_4

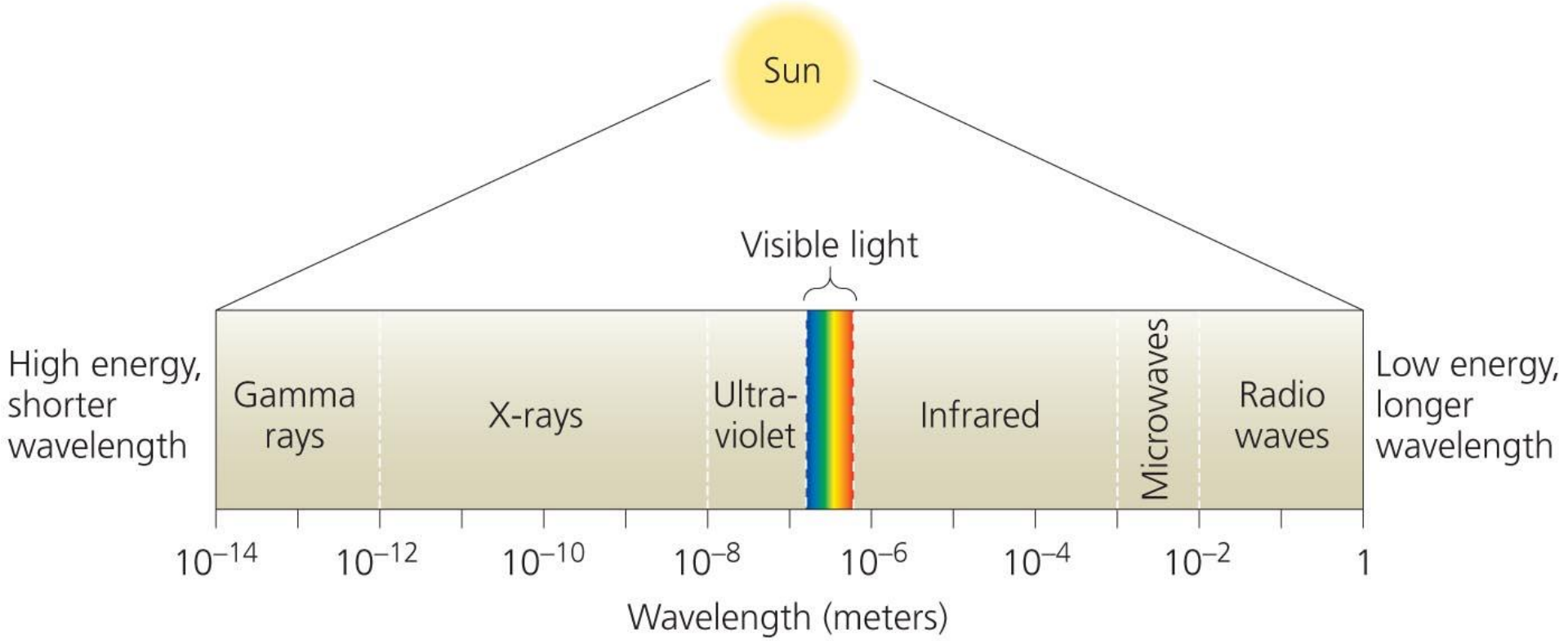
(b) Ethane, C_2H_6

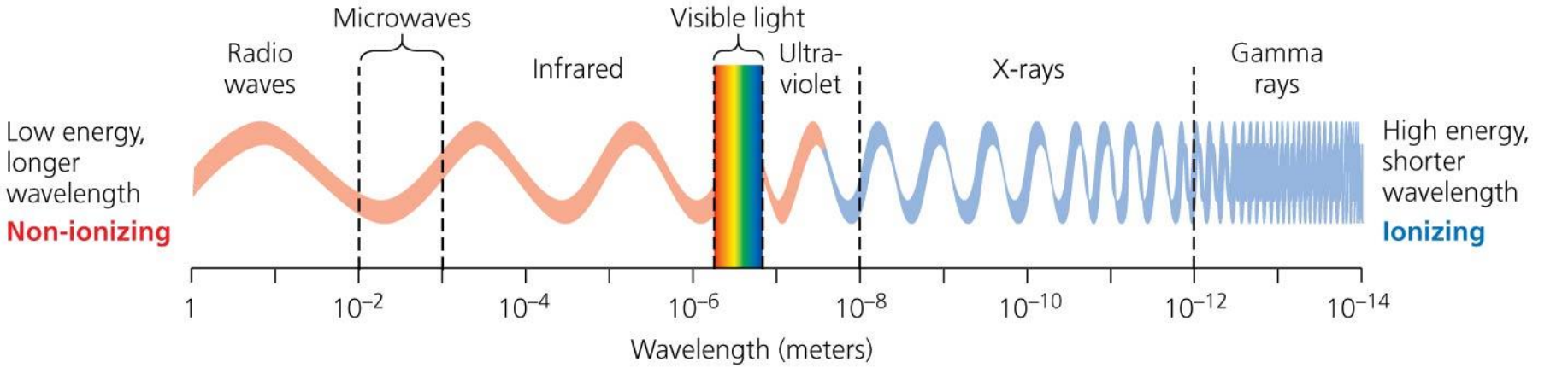
(c) Naphthalene, $C_{10}H_8$

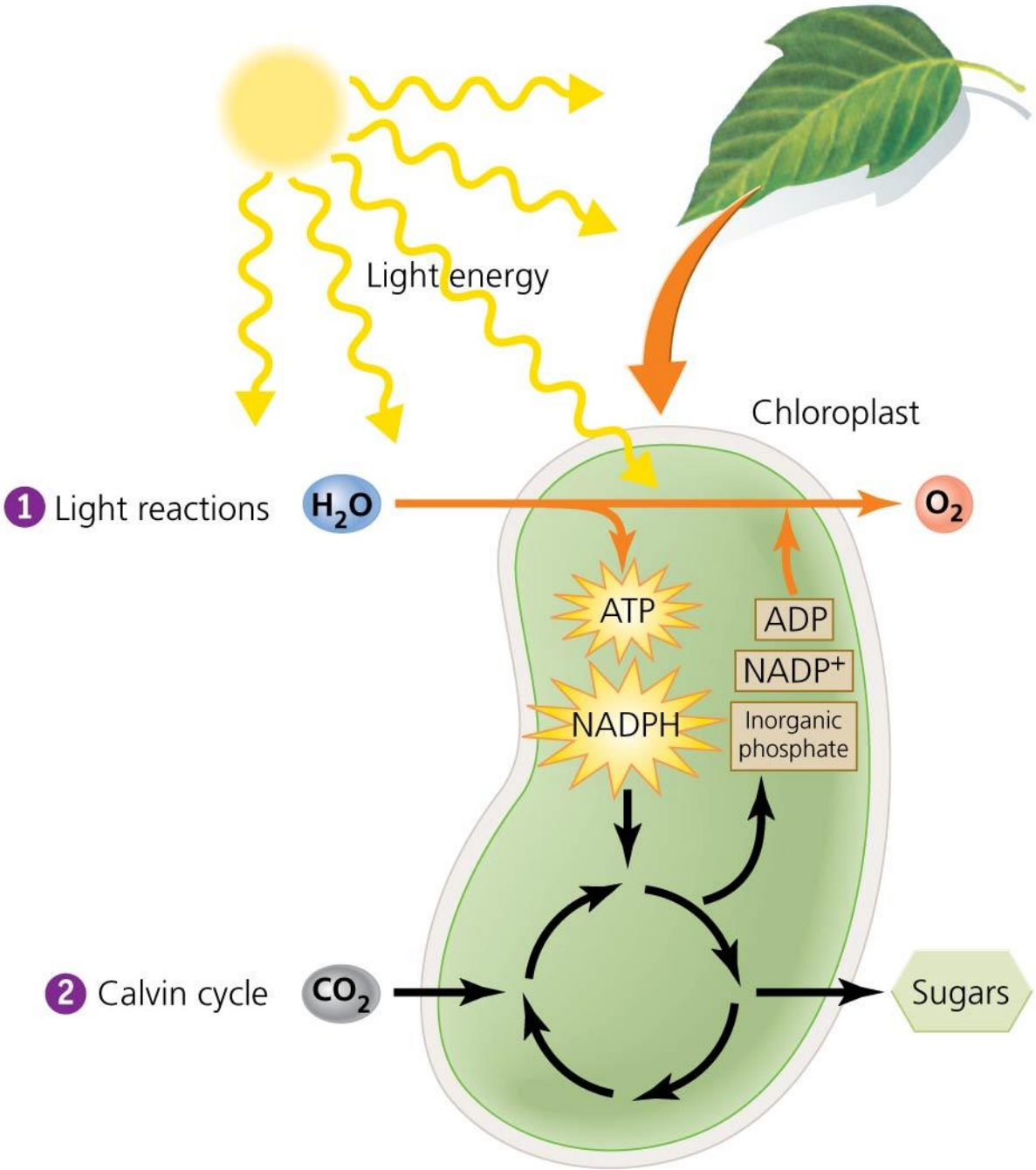

Phosphate group
Sugar
Nitrogenous base
(a) DNA nucleotide
Nitrogenous base
Sugar-phosphate backbone
T
A
G
C
A
T
(b) DNA double helix

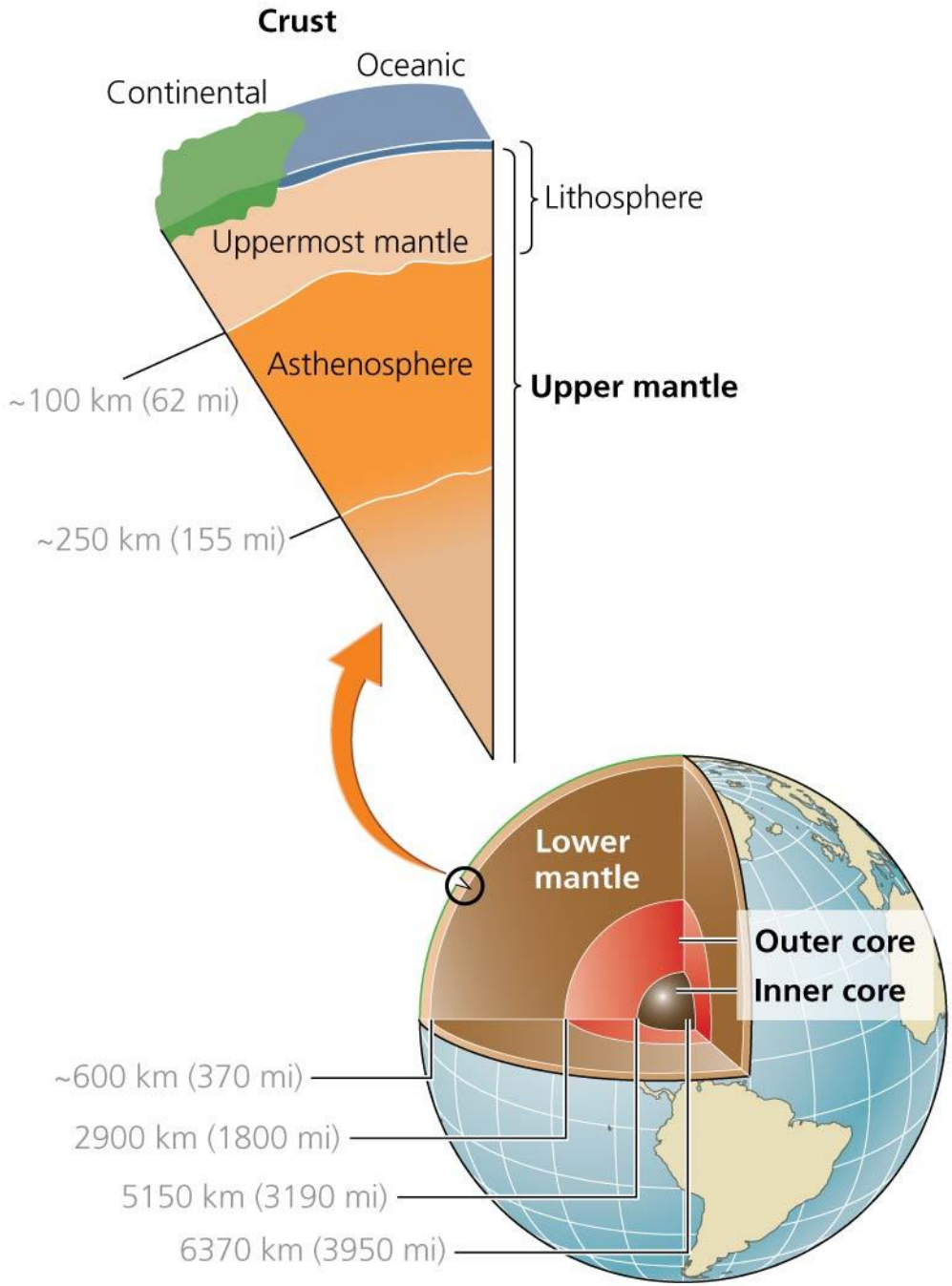

Potential energy
Kinetic energy
Food molecules
$C_6H_{12}O_6$
Glucose
+
O_2
Oxygen
CO_2
Carbon dioxide
+
H_2O
Water
+
Heat

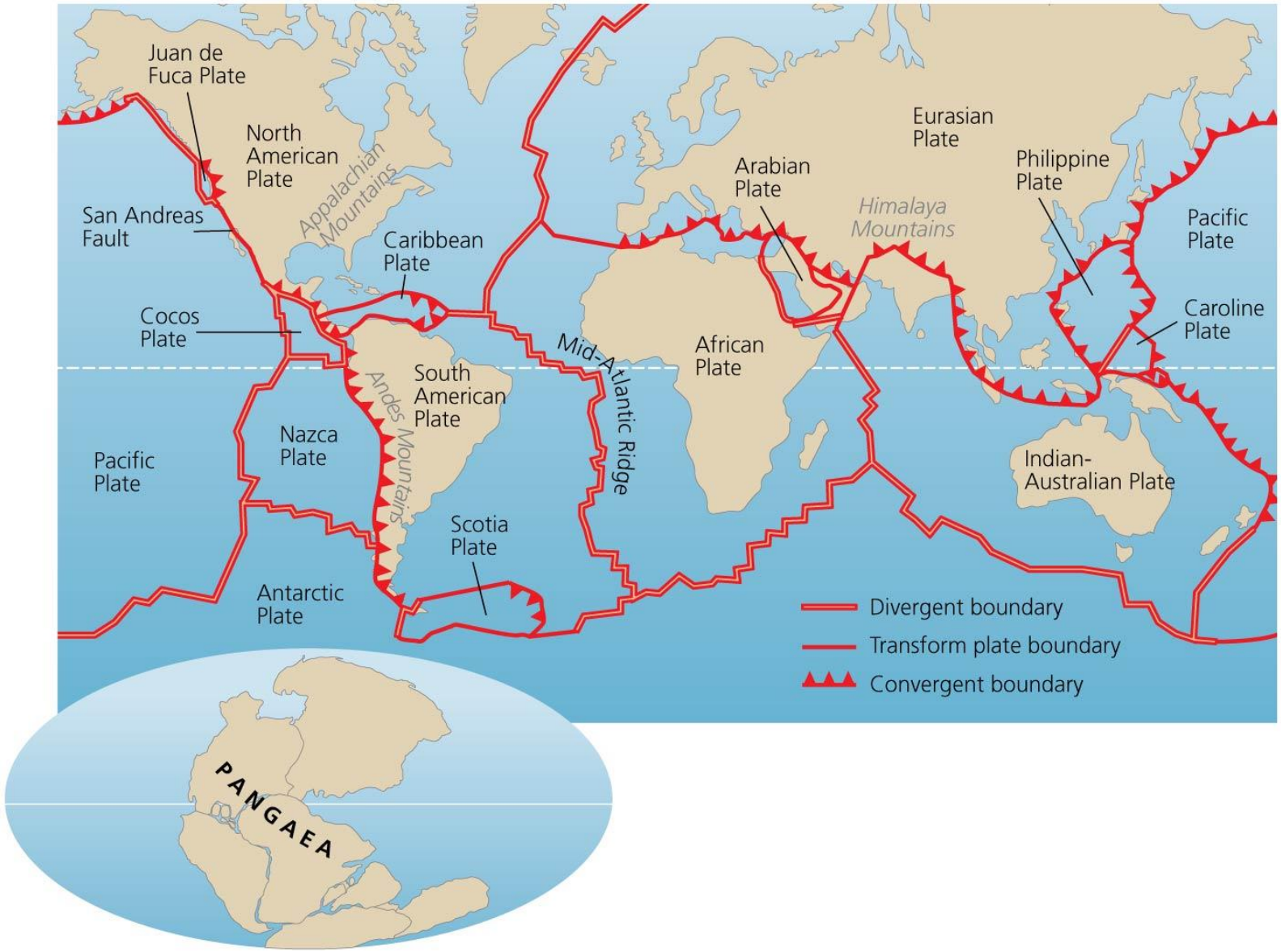

CO_2
H_2O
Light
Heat
Potential energy
(stored in the molecular
bonds of wood)
Kinetic energy
(released as heat and light)
Increase in entropy

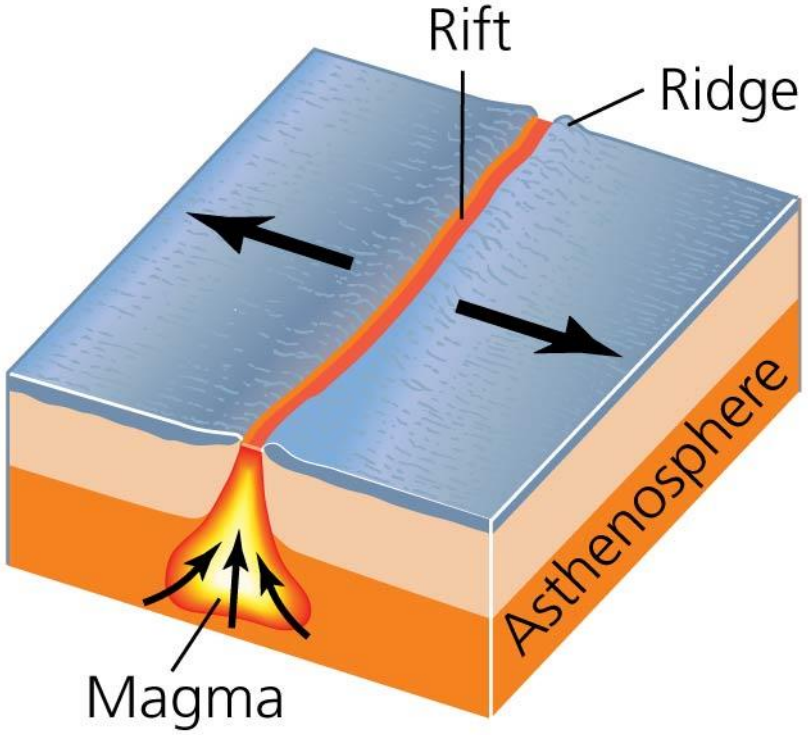




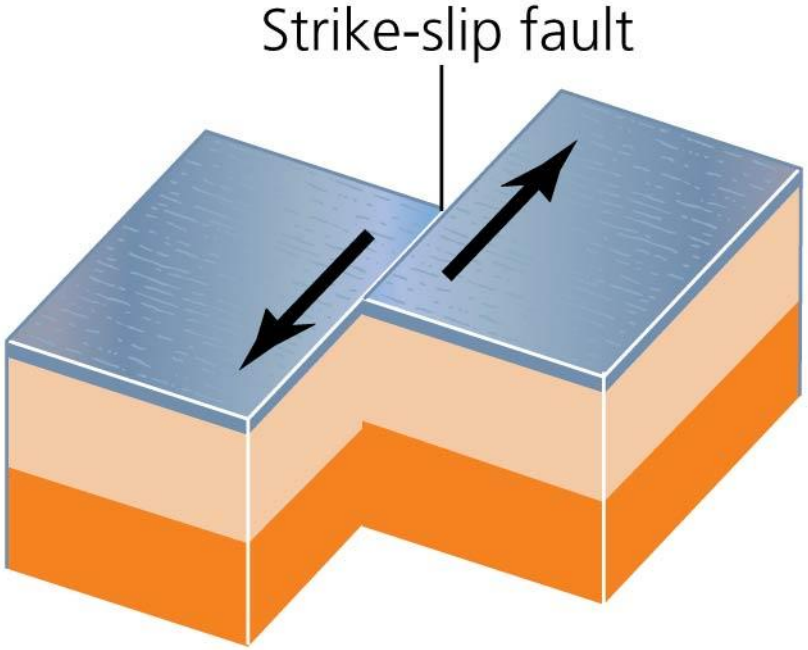

Light energy
Chloroplast
1 Light reactions
H_2O
O_2
ATP
ADP
$NADP^+$
NADPH
Inorganic phosphate
2 Calvin cycle
CO_2
Sugars


Crust
Oceanic
Continental
Lithosphere
Uppermost mantle
Asthenosphere
~100 km (62 mi)
Upper mantle
~250 km (155 mi)
Lower mantle
Outer core
Inner core
~600 km (370 mi)
2900 km (1800 mi)
5150 km (3190 mi)
6370 km (3950 mi)

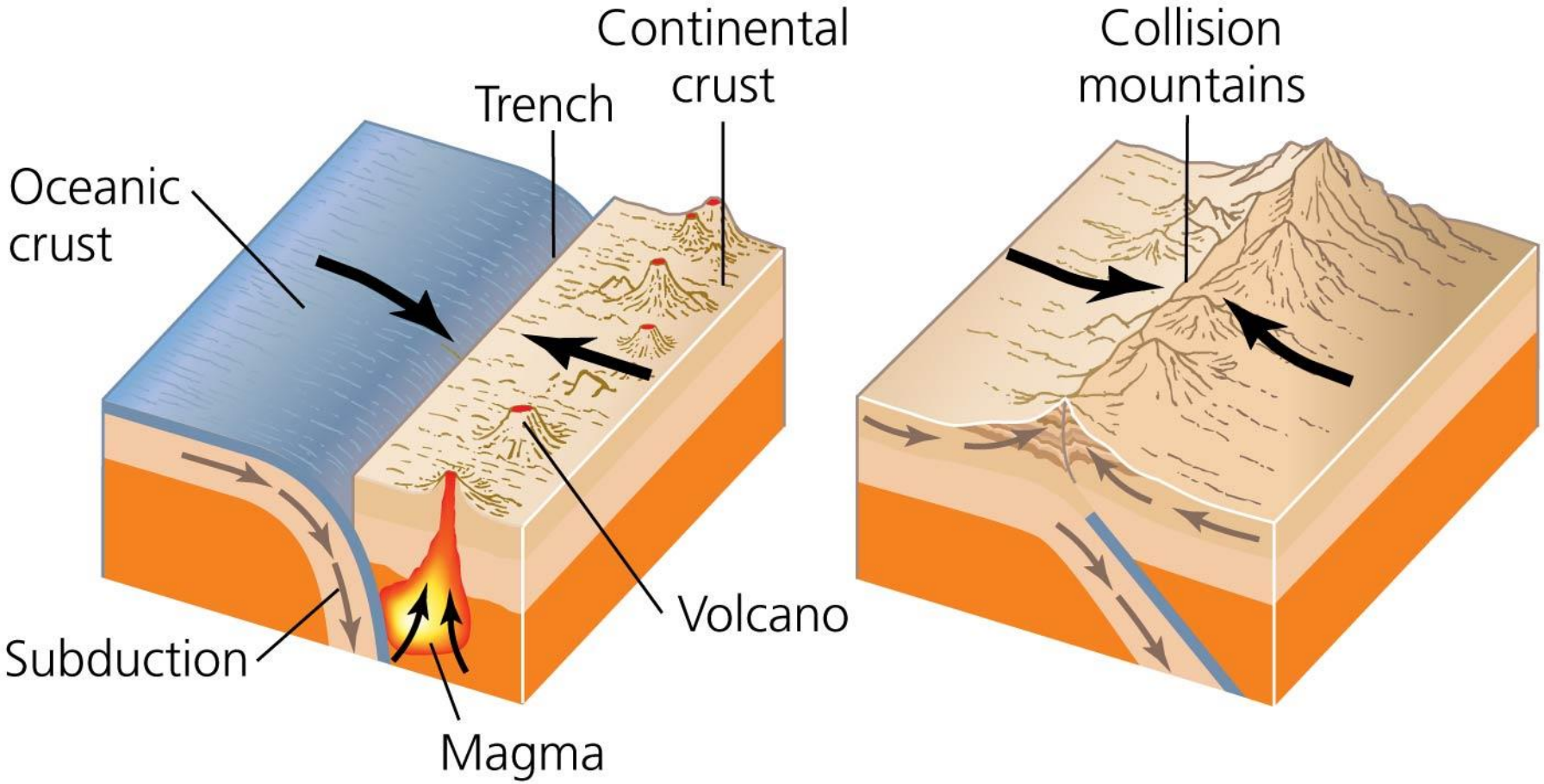

Juan de Fuca Plate
North American Plate
Appalachian Mountains
San Andreas Fault
Caribbean Plate
Cocos Plate
Nazca Plate
Pacific Plate
South American Plate
Andes Mountains
Scotia Plate
Antarctic Plate
Mid-Atlantic Ridge
African Plate
Arabian Plate
Eurasian Plate
Himalaya Mountains
Philippine Plate
Pacific Plate
Caroline Plate
Indian-Australian Plate
Divergent boundary
Transform plate boundary
Convergent boundary
PANGAEA



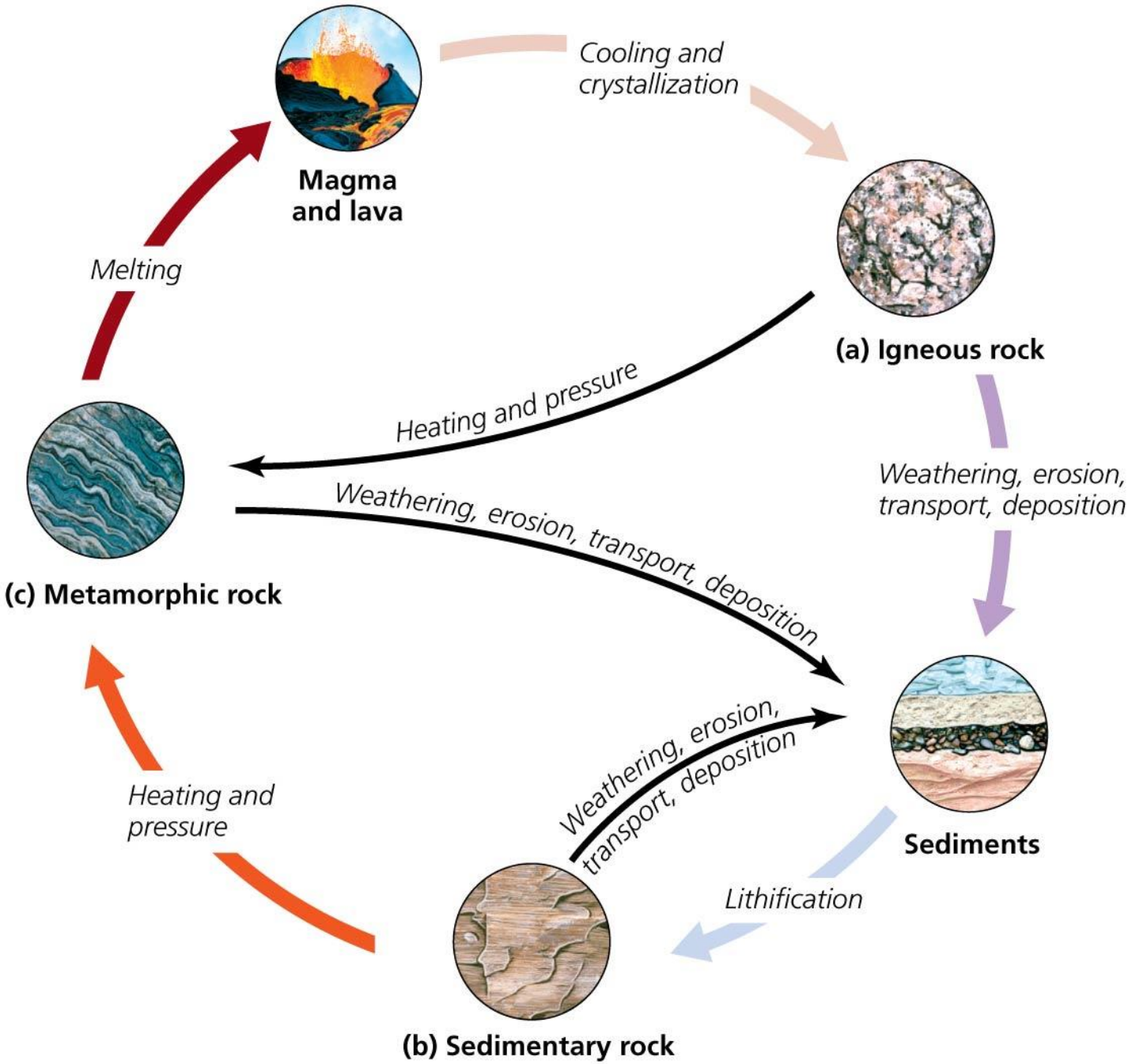
(a) Divergent plate boundary



(b) Transform plate boundary



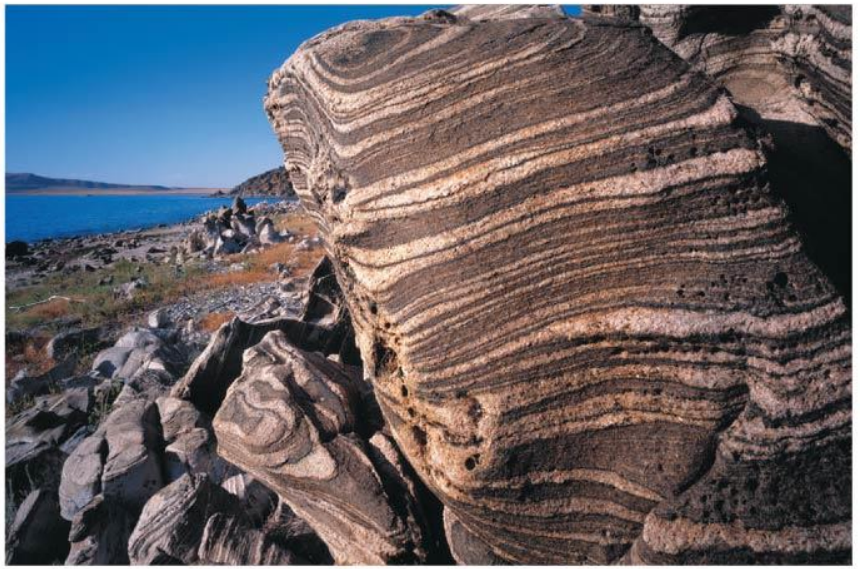
(c) Convergent plate boundary


Magma and lava
Cooling and crystallization
(a) Igneous rock
Weathering, erosion, transport, deposition
Sediments
Lithification
(b) Sedimentary rock
Heating and pressure
Weathering, erosion, transport, deposition
(c) Metamorphic rock
Heating and pressure
Melting

(a) Intrusive igneous rock: Granite at Yosemite National Park

(b) Extrusive igneous rock: Basalt in the Canary Islands

(c) Sedimentary rock: Sandstone in Arizona



(d) Metamorphic rock: Gneiss in Utah

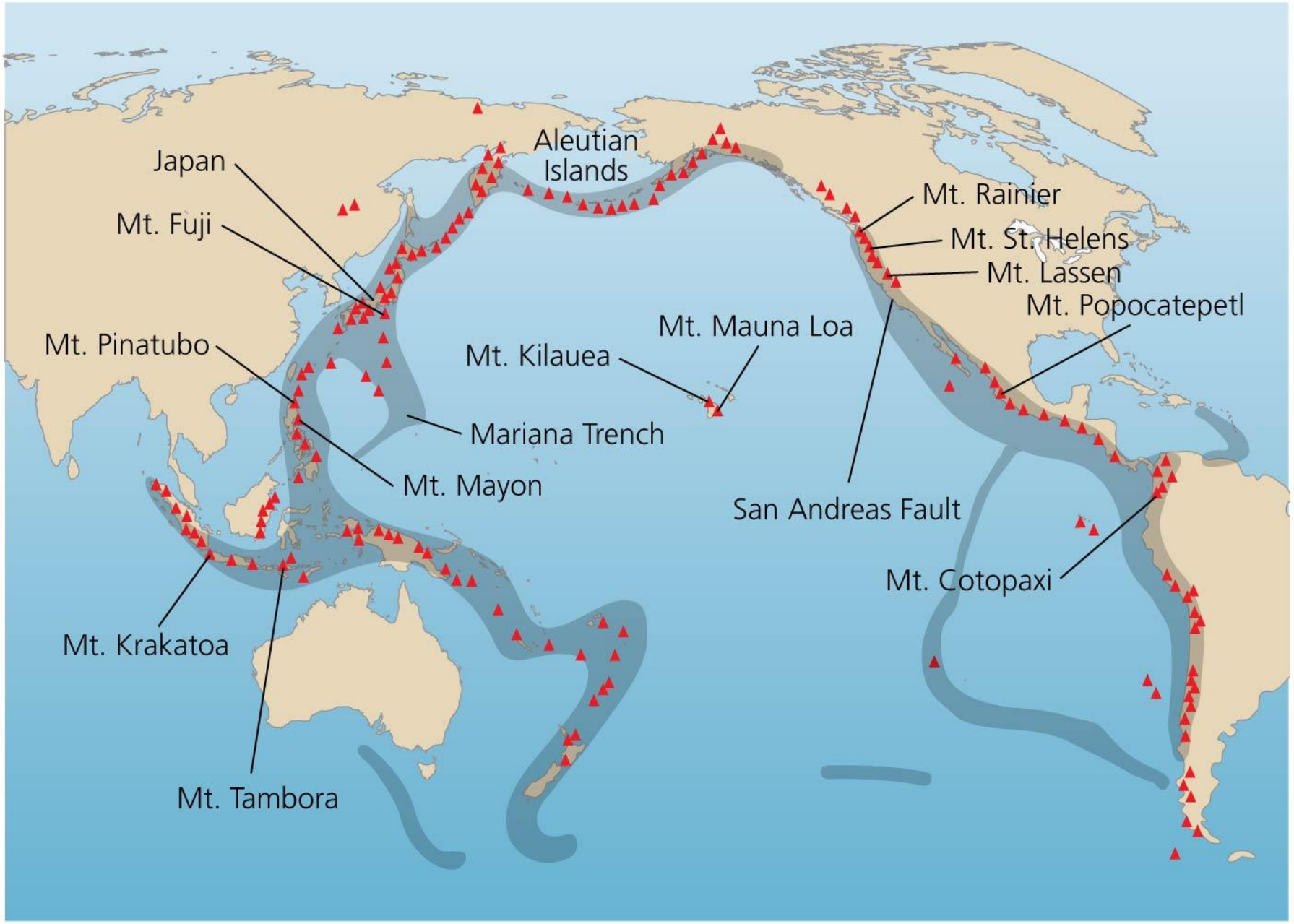
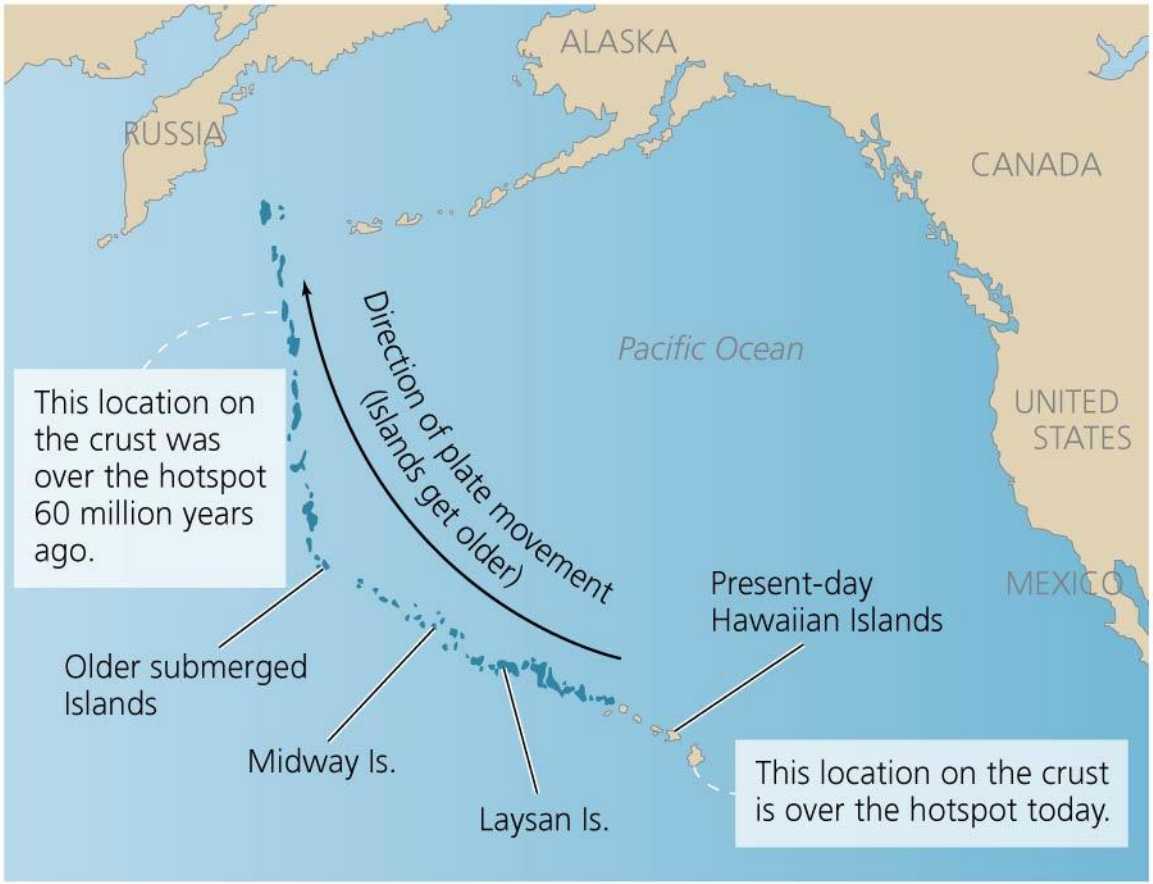

Japan
Mt. Fuji
Aleutian Islands
Mt. Rainier
Mt. St. Helens
Mt. Lassen
Mt. Popocatepetl
Mt. Pinatubo
Mt. Mauna Loa
Mt. Kilauea
Mariana Trench
Mt. Mayon
San Andreas Fault
Mt. Cotopaxi
Mt. Krakatoa
Mt. Tambora

TABLE 2.2 Examples of Large or Recent Earthquakes

Year	Location	Fatalities	Magnitude[1]
1556	Shaanxi Province, China	830,000	~8
1755	Lisbon, Portugal	70,000[2]	8.7
1906	San Francisco, California	3,000	7.8
1923	Kwanto, Japan	143,000	7.9
1964	Anchorage, Alaska	128[2]	9.2
1976	Tangshan, China	255,000+	7.5
1985	Michoacan, Mexico	9,500	8.0
1989	Loma Prieta, California	63	6.9
1994	Northridge, California	60	6.7
1995	Kobe, Japan	5,502	6.9
2004	Northern Sumatra	228,000[2]	9.1
2005	Kashmir, Pakistan	86,000	7.6
2008	Sichuan Province, China	50,000+	7.9
2010	Port-au-Prince, Haiti	236,000	7.0
2010	Maule, Chile	500	8.8
2011	Northern Japan	19,000[2]	9.0

[1]*Measured by moment magnitude; each full unit is roughly 32 times as powerful as the preceding full unit.*

[2]*Includes deaths from the resulting tsunami.*



(a) Current and former Hawaiian Islands, formed as crust moves over a volcanic hotspot

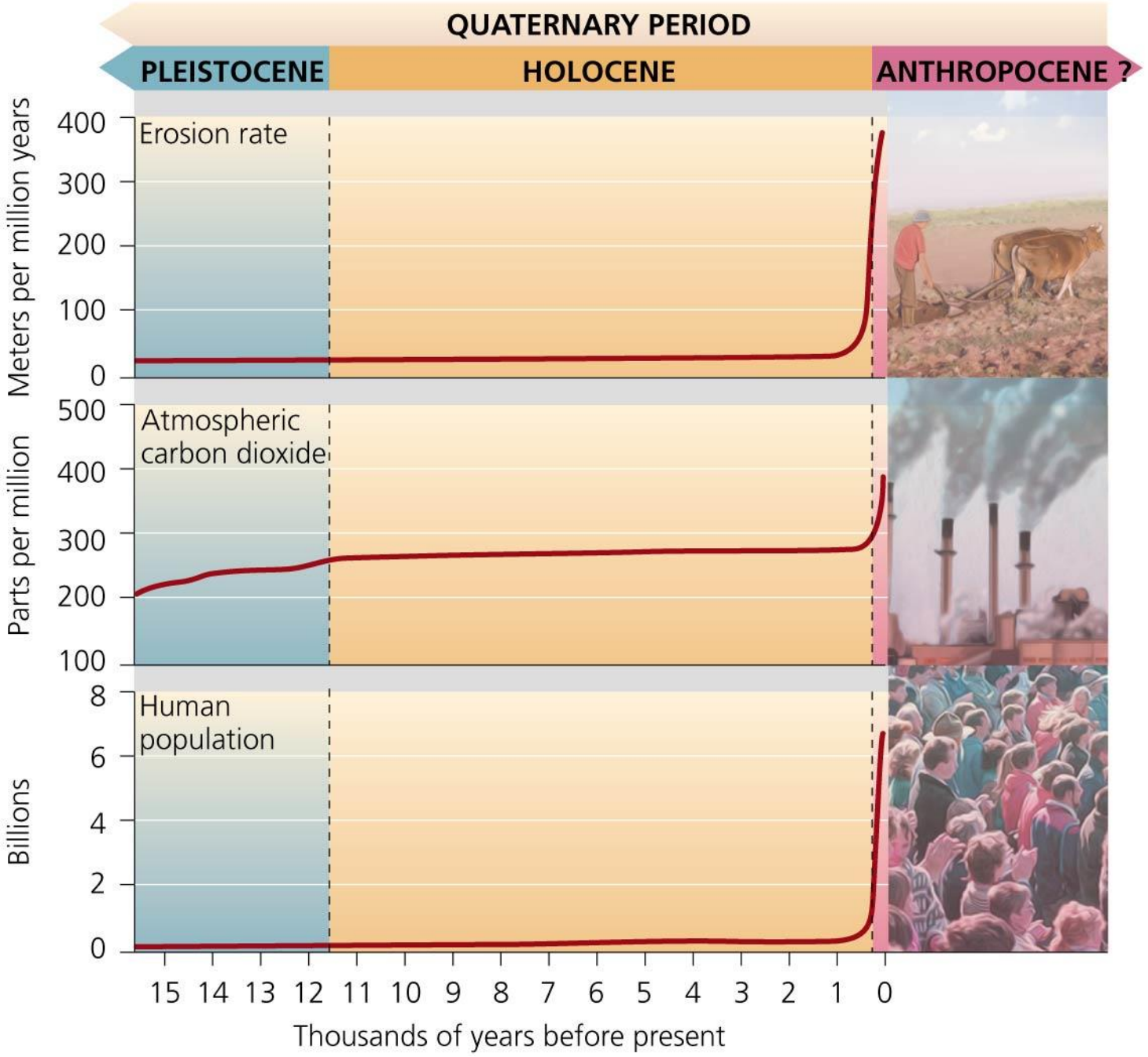
(b) Mt. Kilauea erupting

TABLE 2.3 Examples of Notable Volcanic Eruptions

Year	Location	Impacts	Magnitude[2]
640,000 B.P.[1]	Yellowstone Caldera, Wyoming, U.S.	Most recent "mega-eruption" at site of Yellowstone National Park	8
6870 B.P.	Mount Mazama, Oregon, U.S.	Created Crater Lake	7
A.D. 79	Mount Vesuvius, Italy	Buried Pompeii and Herculaneum	5
1815	Mount Tambora, Indonesia	Created "year without a summer"; killed at least 70,000 people	7
1883	Krakatau, Indonesia	Killed over 36,000 people; heard 5000 km (3000 mi) away; affected weather for 5 years	6
1980	Mount St. Helens, Washington, U.S.	Blew top off mountain; sent ash 19 km (12 mi) into sky and into 11 U.S. states; 57 people killed	5
1983–present	Kilauea, Hawaii, U.S.	Continuous lava flow	1
1991	Mount Pinatubo, Philippines	Sulfuric aerosols lowered world temperature 0.5 °C (0.9 °F)	6
2010	Eyjafjallajokull, Iceland	Ash cloud disrupted air travel throughout Europe	1

[1]B.P. = years before the present.

[2]Measured by the Volcanic Explosivity Index, which ranges from 0 (least powerful) to 8 (most powerful).


QUATERNARY PERIOD
PLEISTOCENE
HOLOCENE
ANTHROPOCENE ?
Erosion rate
Meters per million years
400
300
200
100
0
Atmospheric carbon dioxide
Parts per million
500
400
300
200
100
Human population
Billions
8
6
4
2
0
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Thousands of years before present

Conclusion

- Solving environmental problems depends on understanding matter, chemistry, and energy
- Physical processes of geology (e.g., plate tectonics, the rock cycle) are centrally important
  - They shape terrain and form the foundation of living system
- Geologic processes can threaten us
  - Processes in one location can initiate events whose impacts go far beyond that one location