Introduction to Environmental Sciences:

2. Matter, Energy, and the Physical Environment

Earth 122

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This lecture will help you understand:

- Outline fundamentals of matter and energy
- Summarize the basic types of matter that are building blocks for all materials on Earth
- Differentiate among various types of energy and their roles in environmental systems
- Describe how photosynthesis and cellular respiration turns energy into matter and back again
- Explain how plate tectonics and the rock cycle shape the landscape around us and Earth beneath our feet
- Summarize the main hypothesis for the origin of life

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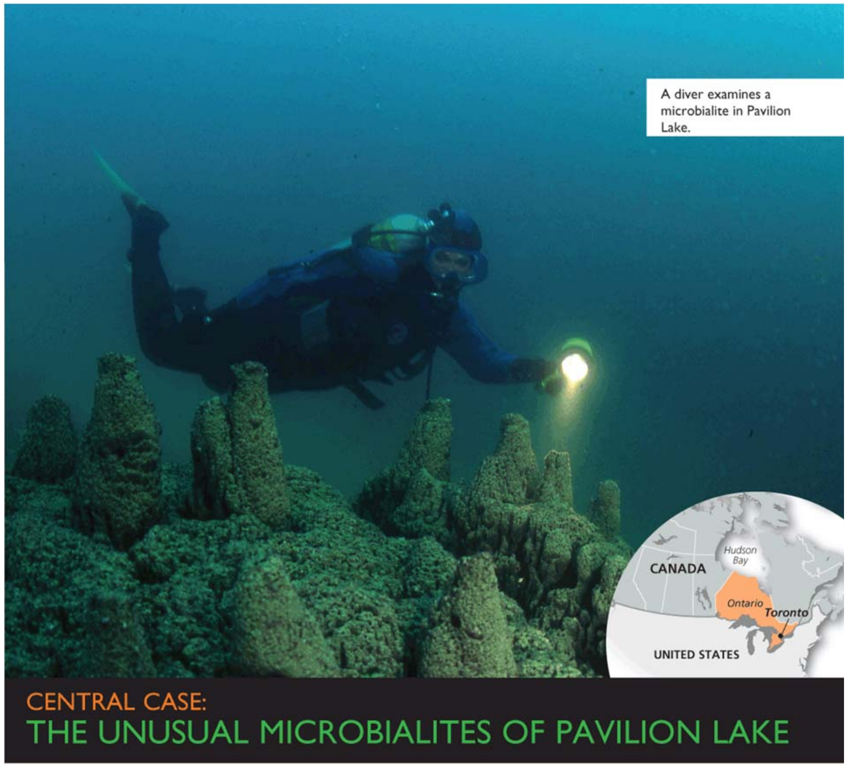
Central Case: The unusual microbialites of Pavilion Lake

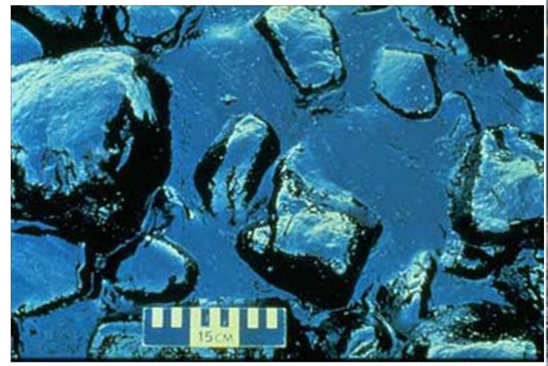
- Microbialites: reeflike sedimentary structures composed of calcium carbonate of organic derivation
- Less well known than oceanic reefs
- Understanding how life-supporting environments originated on Earth depends to a great extent on understanding the formation of carbonate rocks



http://www.pavilionlake.com/

Chemistry is crucial for understanding:

- How gases contribute to global climate change
- How pollutants cause acid rain
- The effects on health of wildlife and people
- Water pollution
- Wastewater treatment
- Atmospheric ozone depletion
- Energy issues




http://en.wikipedia.org/wiki/File:OilPoolFromValdezSpill.jpeg

Matter cannot be created or destroyed

- **Matter** = all material in the universe that has mass and occupies space
  - Can be transformed from one type of substance into others
  - But it cannot be destroyed or created which is…
  - The **law of conservation of matter**
    - Helps us understand that the amount of matter stays constant – implications on waste and pollution
    - It is recycled in nutrient cycles and ecosystems

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Potential Pathways for Oil to Reach Bottom Sediments

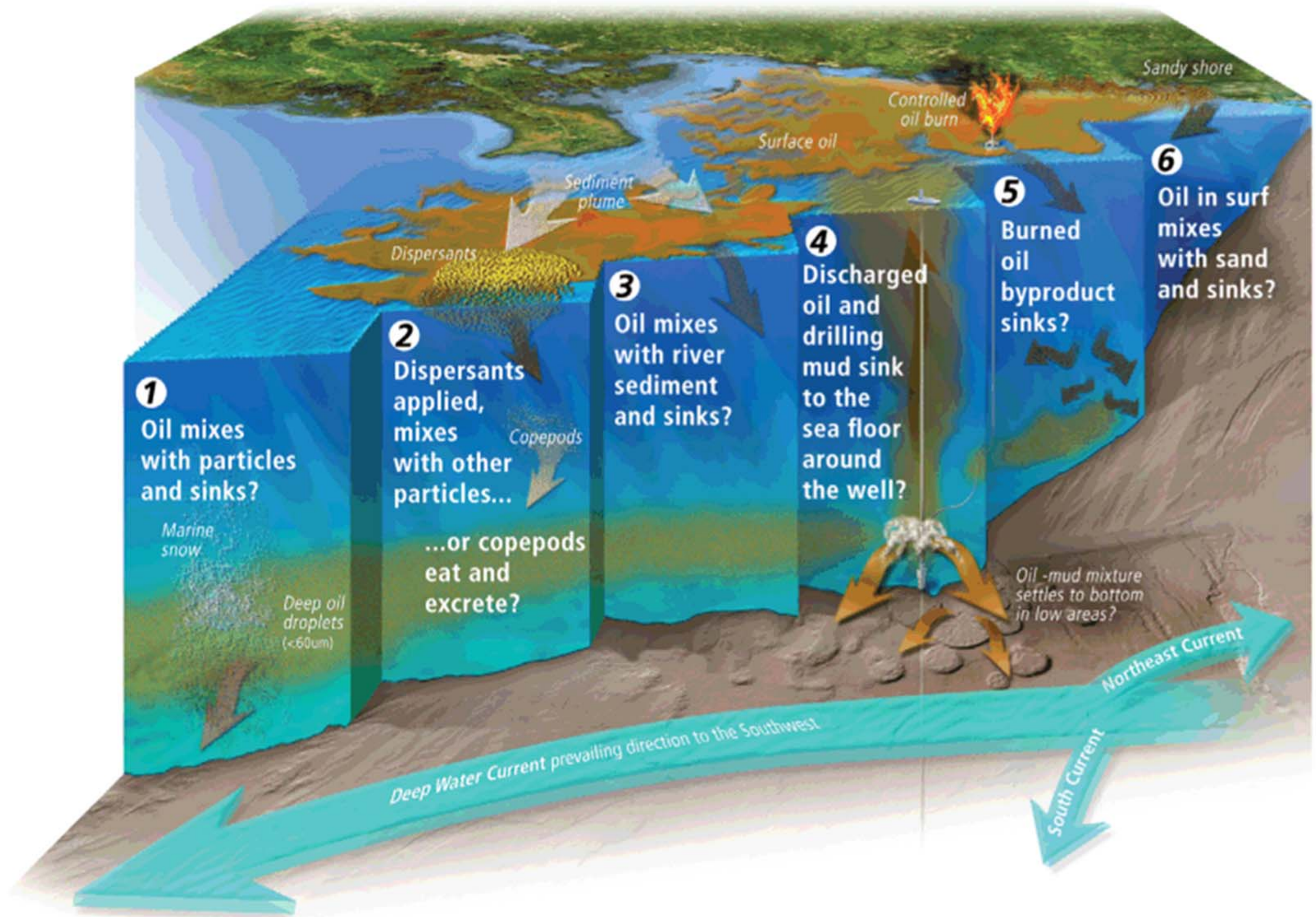

FIGURE 2.1
Matter never just disappears, as much as we might sometimes wish it. In this case, oil that was spilled in the Gulf of Mexico in 2010 has moved around and changed its form, along all of the pathways shown here. All of the oil ended up somewhere—in the rocks and sediments at the bottom of the gulf, or mixed with sediment on the shore, or dispersed in the water, or ingested by marine organisms, or volatilized into the air.

Atoms, isotopes, and ions are chemical building blocks

- **Element** = a fundamental type of matter, with a given set of properties; composed of atoms;
  - **Atoms** = the smallest components that maintain an element's chemical properties
  - The atom's nucleus has **protons** (positively charged particles) and **neutrons** (particles lacking electric charge)
  - **Atomic number** = the defined number of protons
  - **Electrons** **=** negatively charged particles surrounding the nucleus
    - Balances the positively charged protons

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

Earth's crust	Oceans	Air	Organisms
Oxygen (O), 49.5%	Oxygen (O), 85.8%	Nitrogen (N), 78.1%	Oxygen (O), 65.0%
Silicon (Si), 25.7%	Hydrogen (H), 10.8%	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%	Other, 0.4%		Calcium (Ca), 1.5%
Sodium (Na), 2.8%			Phosphorus (P), 1.0%
Potassium (K), 2.6%			Potassium (K), 0.4%
Magnesium (Mg), 2.1%			Sulphur (S), 0.3%
Other, 1.6%			Other, 0.5%

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Atoms, isotopes, and ions are chemical building blocks

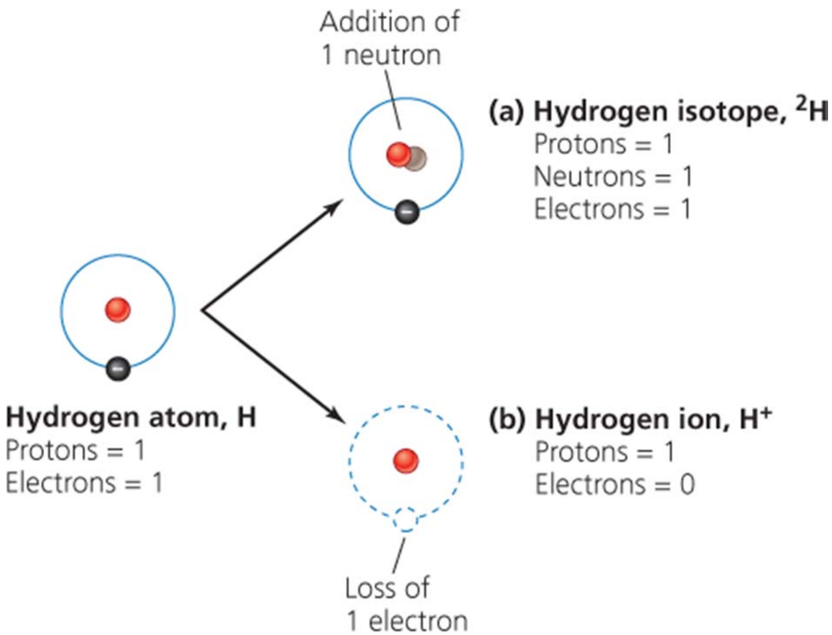

FIGURE 2.2
Hydrogen is an element; it contains 1 proton + 0 neutron (mass number = 1). Deuterium **(a)**, an isotope of hydrogen, contains 1 proton + 1 neutron, and thus has greater mass than a typical hydrogen atom. Because deuterium has 1 proton, it is still a form of hydrogen. If a hydrogen atom loses its one electron **(b)**, it gains a positive charge and becomes a hydrogen ion, H^+.

- **Isotopes** = atoms with differing numbers of neutrons
  - **Mass number** = the combined number of protons and neutrons
  - Isotopes of an element behave differently
  - Some isotopes are **radioactive** and decay until they become non-radioactive **stable isotopes**
    - Emit high-energy radiation

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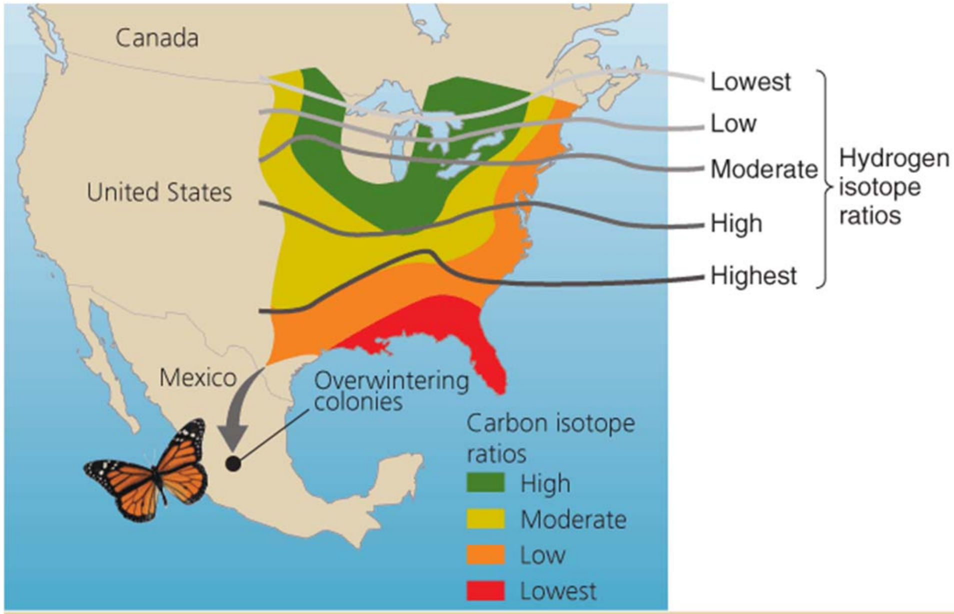
The Science Behind the Story

- How isotopes reveal secrets of Earth and life
  - Scientists have been able to use isotopes to study the flow of nutrients within and among organisms and the movement of organisms from one geographic location to another



Plants in different geographic areas have different carbon and hydrogen isotopic ratios, which caterpillars incorporate into their tissues when they eat the plants. When the caterpillars metamorphose into butterflies and migrate, they carry these isotopic signatures with them. This map of isotopic ratios across eastern North America, produced from measurements of monarch butterflies, shows decreasing ratios of ^{13}C to ^{12}C from north to south (coloured bands) and increasing ratios of ^{2}H to ^{1}H from north to south (grey lines). By measuring carbon and hydrogen isotopic ratios in monarchs wintering in Mexico and matching the numbers against this map, researchers were able to pinpoint the geographic origin of many of the butterflies.
Source: Wassenaar, Wassenaar, L. I., and K. A. Hobson (1998). Proceedings of the National Academy of Sciences of the USA *95:15436–15439.*

Radioactive decay

- **Half-life** = the amount of time it takes for one-half of the atoms to give off radiation and decay
  - Different radioisotopes have different half-lives ranging from fractions of a second to billions of years
  - *Uranium-235, used in commercial nuclear power, has a half-life of 700 million years; problematic in terms of nuclear waste disposal*
- Atoms may also gain or lose electrons to become **ions**, electrically charged atoms

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Storage/Disposal of Nuclear Waste

http://en.wikipedia.org/wiki/Yucca_Mountain_nuclear_waste_repository

Atoms bond to form molecules & compounds

- **Molecules** = Combinations of two or more atoms; can contain one element or several.
  - Nitrogen gas = N_2; Oxygen gas = O_2
- **Compounds** = A molecule composed of atoms of two or more different elements
  - Water = two hydrogen atoms bonded to one oxygen atom: H_20
  - Carbon dioxide = one carbon atom with two oxygen atoms: CO_2

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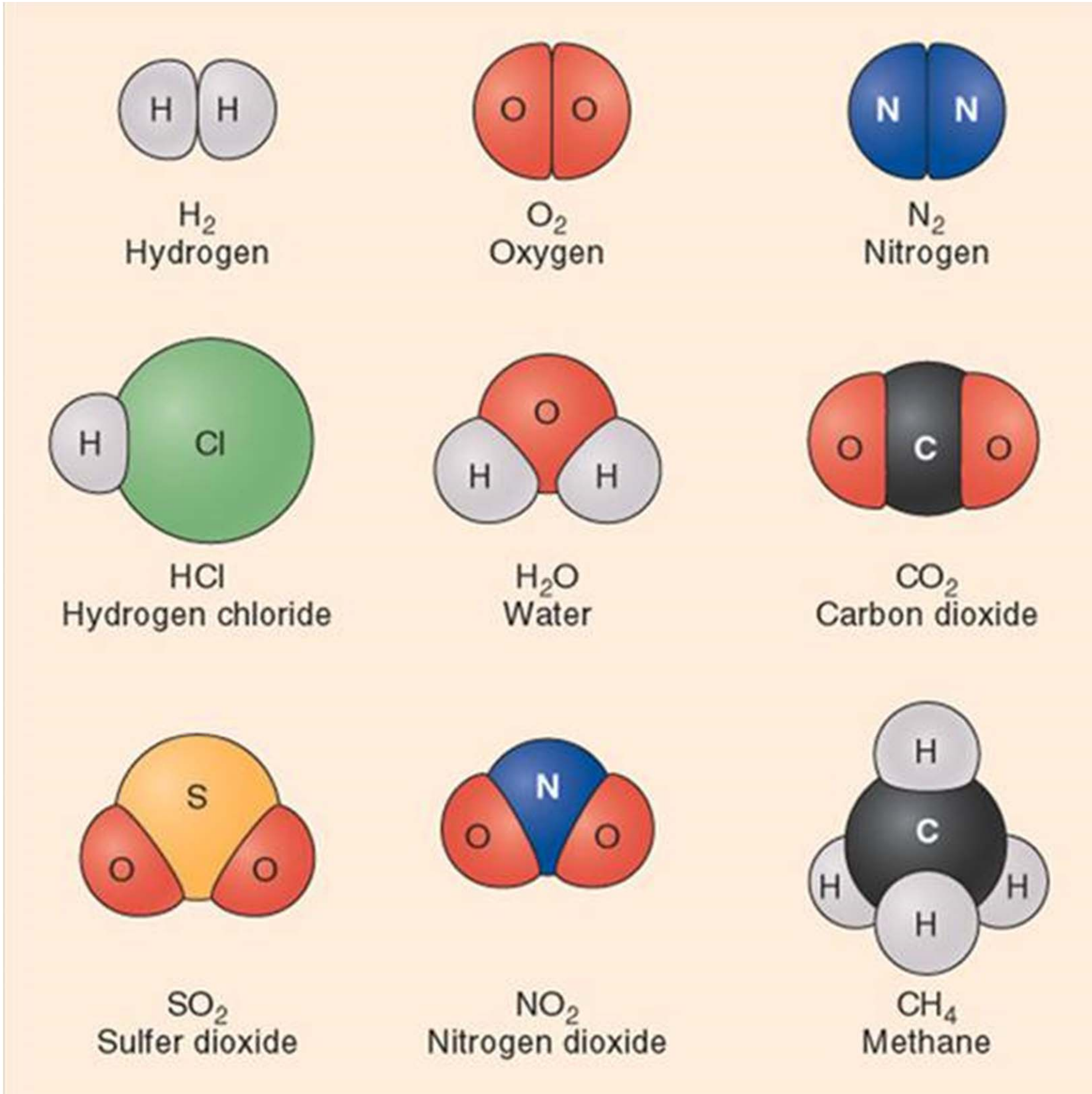
H H
H_2
Hydrogen
O O
O_2
Oxygen
N N
N_2
Nitrogen
H Cl
HCl
Hydrogen chloride
O H H
H_2O
Water
O C O
CO_2
Carbon dioxide
S O O
SO_2
Sulfer dioxide
N O O
NO_2
Nitrogen dioxide
H C H H H
CH_4
Methane

Atoms bond to form molecules & compounds

- **Covalent bond =** atoms in a molecule share electrons
  - For example, the atoms that bond to form H_20
- **Polar covalent bonds =** Atoms share electrons unequally, with one atom exerting a greater pull
  - The oxygen in a water molecule attracts electrons
- **Ionic bonds** = an electron is transferred from one atom to another
  - E.g., salts, such as table salt, NaCl
- **Solutions** = no chemical bonding, but is a mixture of substances (i.e., blood, oil)

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The chemical structure of the water molecule facilitates life

- **Hydrogen bond** causes oxygen from one water molecule to be attracted to the hydrogen atoms of another
- Water's strong cohesion allows nutrients & waste to be transported; high surface tension
- Water absorbs heat with only small changes in its temperature, which stabilizes systems (high heat capacity)
- Water remains liquid over a wide range of temperature

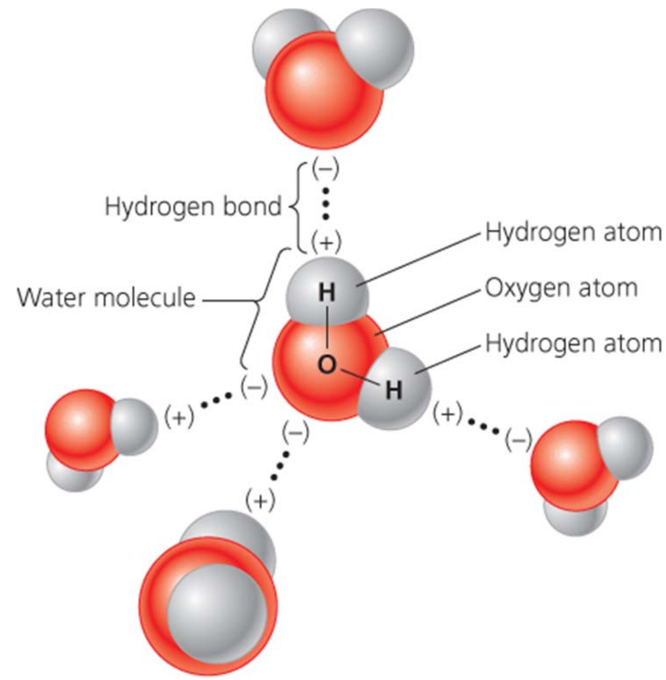

FIGURE 2.3
Water is a unique compound that has several properties crucial for life. Shown here, hydrogen bonds give water cohesion by enabling water molecules to adhere loosely to one another.

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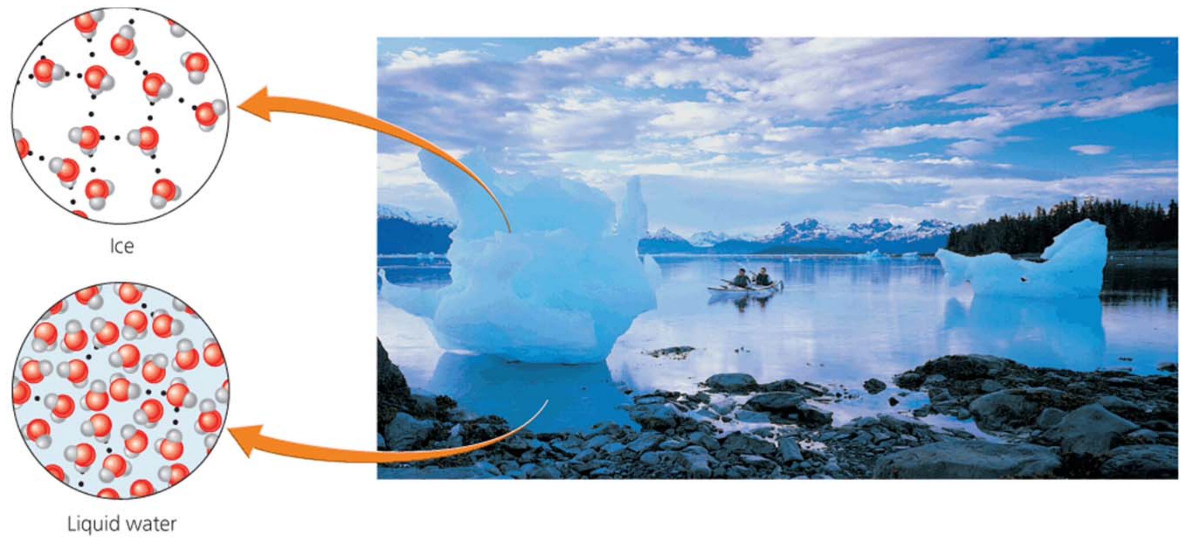
The chemical structure of the water molecule facilitates life

- Less dense ice floats on liquid water
- Water dissolves other molecules
- Water molecules bond well with other polar molecules



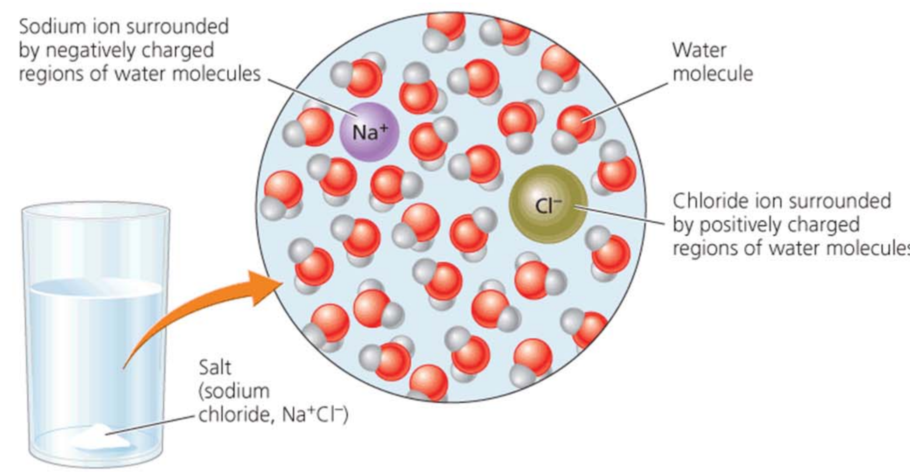


FIGURE 2.4
(a) Ice floats on water because solid ice is less dense than liquid water. This is an unusual property of H_2O—it is far more common for the solid form of a material to be denser than the liquid form.
(b) Water can dissolve many chemicals, especially polar and ionic compounds. Seawater holds sodium and chloride ions, among others, in solution.

Hydrogen ions control acidity

- The pH scale ranges from 0 to 14 and quantifies the acidity of solutions
  - **Acidic** solutions have a pH less than 7
  - **Basic** solutions have a pH greater than 7
  - **Neutral** solutions have a pH of 7

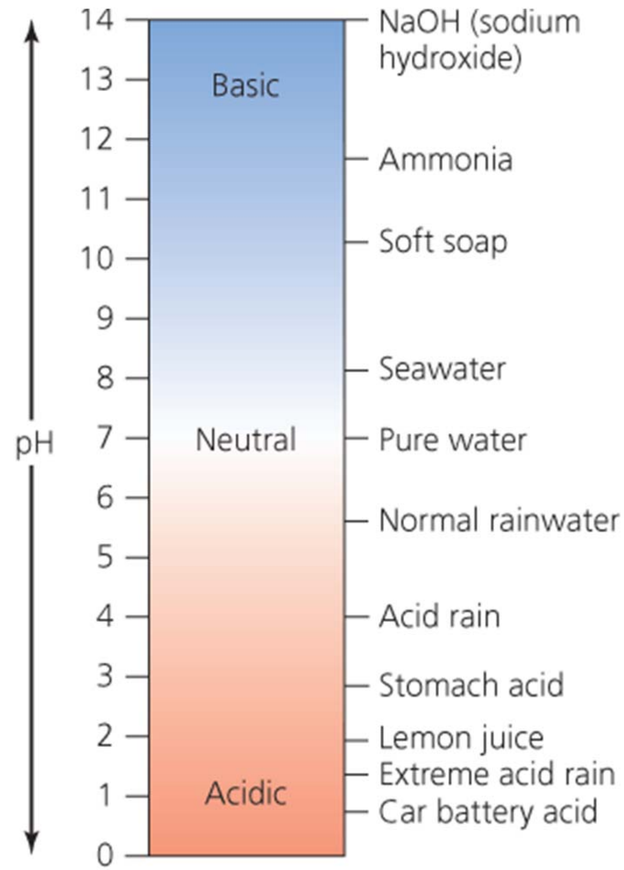


FIGURE 2.5
The pH scale measures how acidic or basic a solution is. The pH of pure water is 7, the midpoint of the scale. Acidic solutions have higher hydrogen ion concentrations and lower pH, whereas basic solutions have lower hydrogen ion concentrations and higher pH.

Matter is composed of organic and inorganic compounds

- **Organic compounds** = carbon atoms joined by covalent bonds and may include other elements
  - Such as nitrogen, oxygen, sulfur, and phosphorus
- **Inorganic compounds** = lack carbon-carbon bonds but may contain carbon
  - Water (H_20) and carbon dioxide (CO_2) are examples

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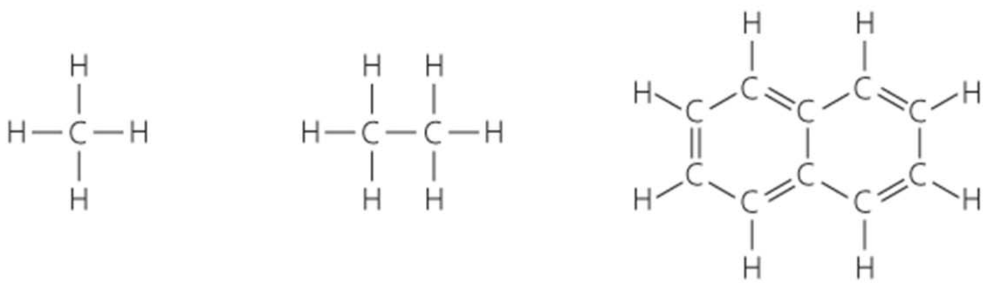
Matter is composed of organic and inorganic compounds

- **Hydrocarbons** = contain only carbon and hydrogen
  - The simplest hydrocarbon is methane
  - Hydrocarbons can be a gas, liquid, or solid



(a) Methane, CH_4

(b) Ethane, C_2H_6

(c) Naphthalene, $C_{10}H_8$ (a polycyclic aromatic hydrocarbon)

FIGURE 2.6
The simplest hydrocarbon is methane **(a)**. Many hydrocarbons consist of linear chains of carbon atoms with hydrogen atoms attached; the shortest of these is ethane **(b)**. Volatile hydrocarbons with multiple rings, such as naphthalene **(c)**, are called polycyclic aromatic hydrocarbons (PAHs).

Macromolecules are building blocks of life

- **Polymers** = long chains of repeated molecules
  – The building blocks of life
- **Macromolecules** = large-size molecules
  – Three types of polymers are essential to life
    - **Proteins**
    - **Nucleic acids**
    - **Carbohydrates**
  – **Lipids** (are not polymers, but are also essential)

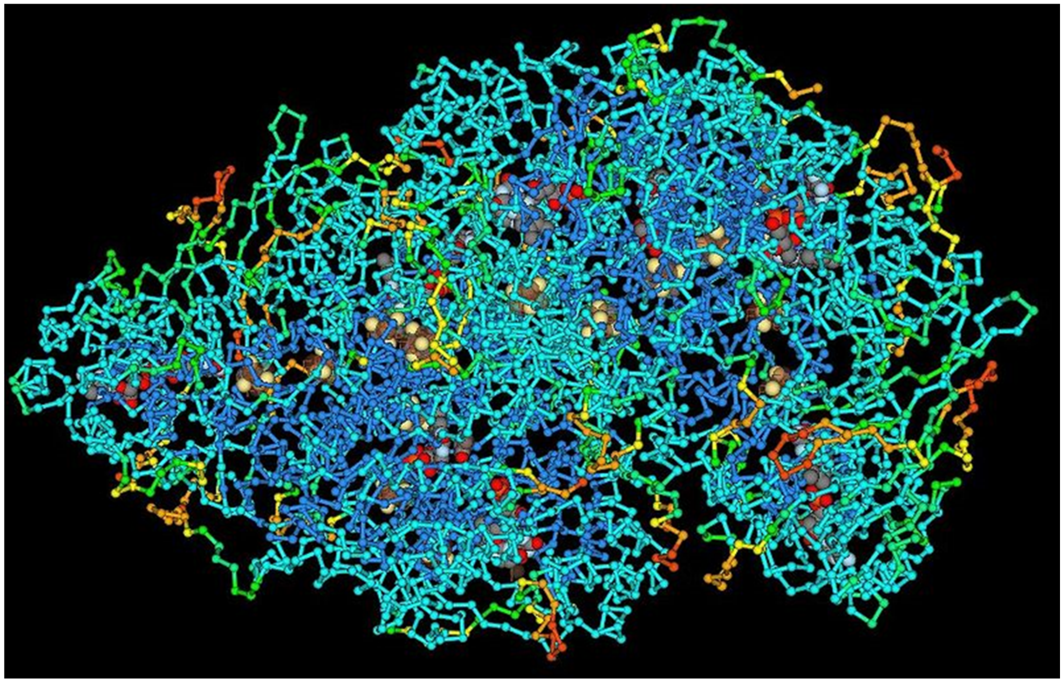


Illustration of a polypeptide macromolecule

http://en.wikipedia.org/wiki/Macromolecule

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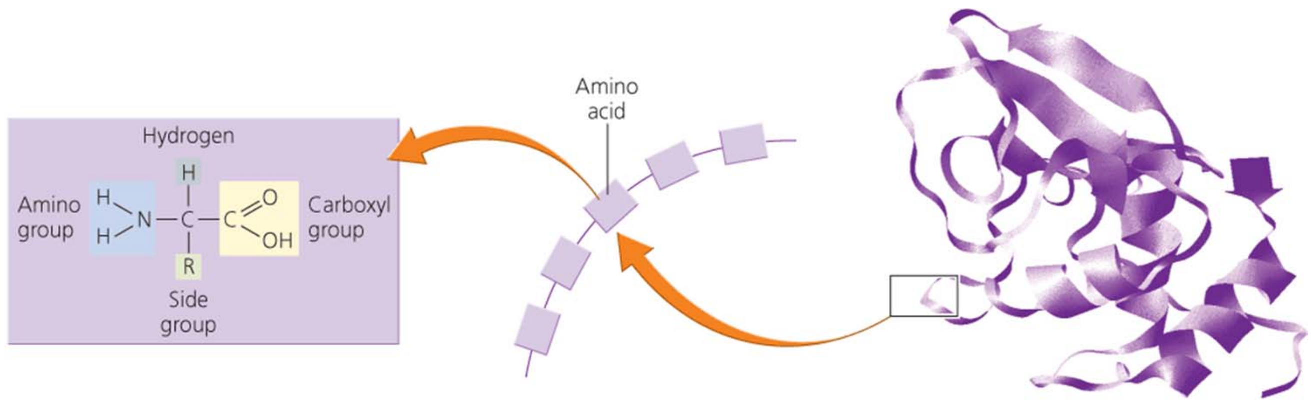
Macromolecules are building blocks of life

- **Proteins**: produce tissues, provide structural support, store and transport energy
  – Animals use proteins to generate skin, hair, muscles, and tendons
  – Some function as components of the immune system
  – They can serve as **enzymes**, molecules that promote certain chemical reactions



(a) General structure of an amino acid (b) Chain of amino acids (c) Protein

FIGURE 2.7 Proteins are polymers that are vital for life. They are made up of long chains of amino acids **(a, b)** that form complex convoluted shapes **(c)**, which help determine their functions.

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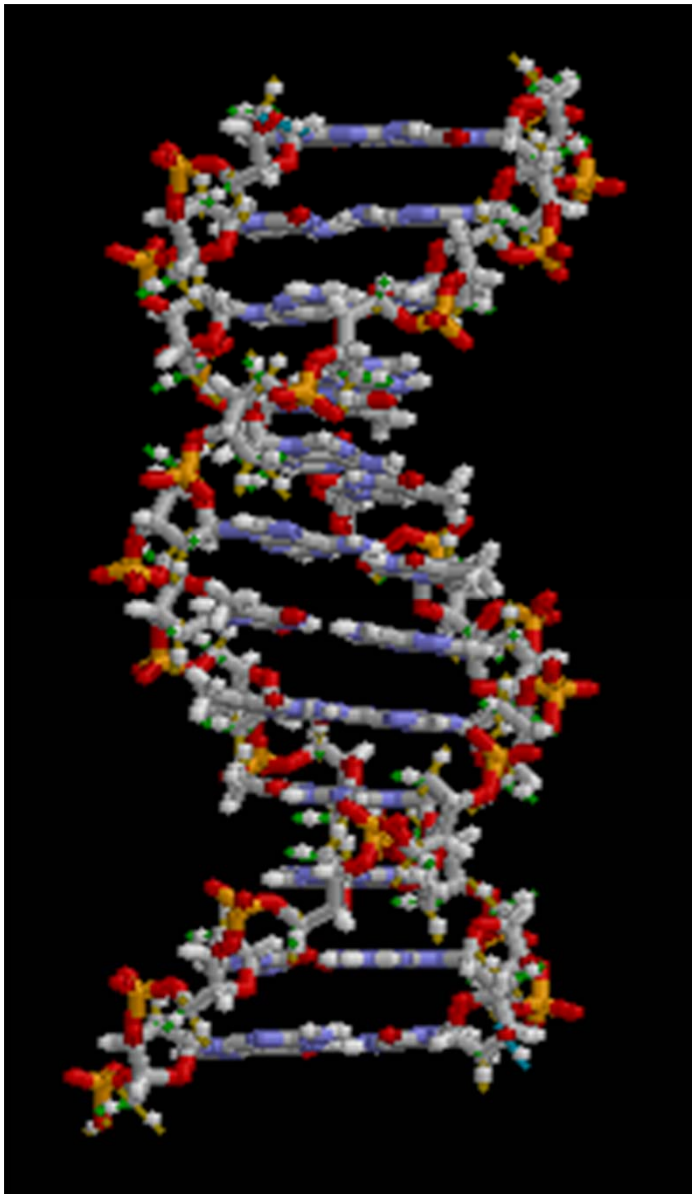
Protein production is directed by nucleic acids

- **Deoxyribonucleic acid (DNA)** and **Ribonucleic Acid (RNA)** carry the hereditary information of organisms
  - Long chains of nucleotides that contain sugar, phosphate, and a nitrogen base
- Information in DNA is rewritten to RNA
- RNA directs amino acid assembly into proteins
- **Genes** = regions of DNA that code for proteins that perform certain functions
- **Genome** = an organism's genes
  - Divided into chromosomes



Macromolecules are building blocks of life

- **Carbohydrates** = consist of atoms of carbon, hydrogen, and oxygen
  - Sugars = simple carbohydrates
    - Glucose = provides energy for cells
  - Complex carbohydrates build structures and store energy
    - Starch = a complex carbohydrate
- **Lipids** = a chemically diverse group of compounds grouped together because they don't dissolve in water
  - For energy, cell membranes, structural support, and steroids

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We create synthetic polymers

- **Plastics** = synthetic (human-made) polymers
  - Best known by their brand names (Nylon, Teflon, Kevlar)
  - Many are derived from petroleum hydrocarbons
  - Valuable because they resist chemical breakdown
  - Problematic because they cause long-lasting waste and pollution
    - Wildlife and health problems, water quality issues, harmful to marine animals
  - We must design less-polluting alternatives and increase recycling

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Energy is always conserved but can change in quality

- Matter is the building material, and energy is the driver of Earth's environmental processes.
- **Energy:** Capacity to change the position, physical composition, or temperature of matter – a force that can accomplish work
- **Potential energy** = energy of position
- **Kinetic energy** = energy of motion
- **Chemical energy** = potential energy held in the bonds between atoms

FIGURE 2.8 Energy is released when potential energy is converted to kinetic energy. Potential energy stored in sugars, such as glucose, in the food we eat **(a)**, combined with oxygen, becomes kinetic energy when we exercise **(b)**, releasing carbon dioxide, water, and heat as by-products.

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Energy is always conserved…but can change in form and quality

- **Energy**: can change from one form to another, it cannot be created or destroyed, thus the total energy in the universe remains constant
  - **First Law of Thermodynamics**
- **Second Law of Thermodynamics**: the nature of energy will change from a more ordered state to a less-ordered state, if not force counteracts this
- **Entropy =** systems tend to move toward increasingly disorder

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People harness energy

- An energy source's nature determines how easily energy can be harnessed
  - Petroleum provide large amounts of efficient energy
  - Sunlight provides low-quality energy, because it is spread out and difficult to harness
- **Energy conversion efficiency** = the ratio of useful energy output to the amount needing to be input
  - An engine burns petroleum to power a car, but most energy is lost as heat

Energy availability and energy policy

Contrast the ease of harnessing concentrated energy, such as that of petroleum, with the ease of harnessing highly diffuse energy, such as that of heat from the oceans.

- How do you think these differences have affected our society's energy policy and energy sources through the years?

Light energy from the Sun powers most living systems

- The Sun releases radiation from the electromagnetic spectrum
  - Some is visible light
  - Most energy is reflected or absorbed
- Solar energy drives weather and climate, and powers plant growth

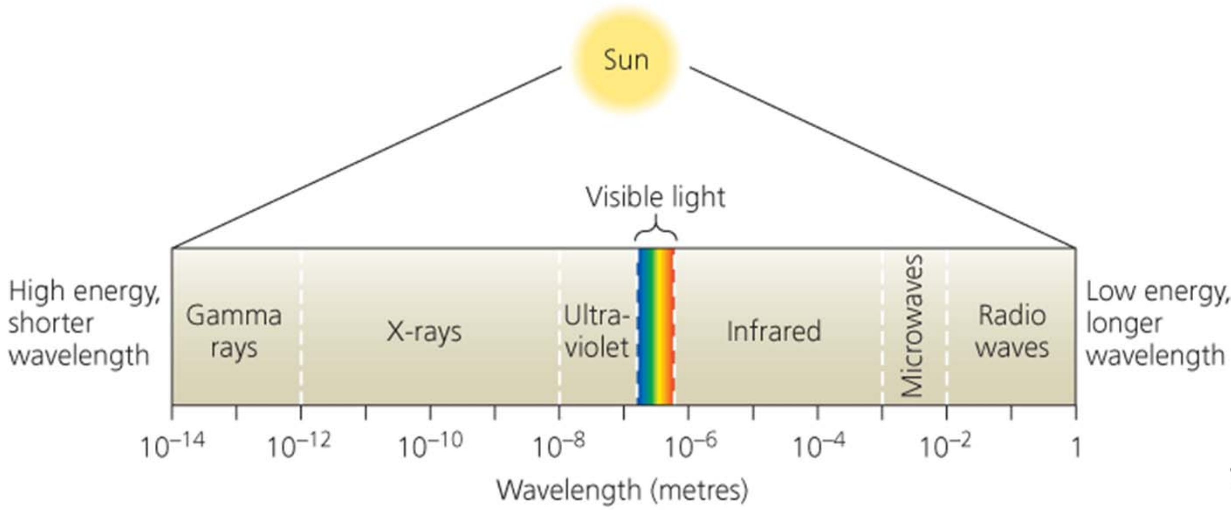

FIGURE 2.9 The Sun emits radiation from many portions of the electromagnetic spectrum. Visible light makes up only a small portion of this energy. Some radiation that reaches our planet is reflected back; some is absorbed by air, land, and water; and a small amount powers photosynthesis.

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Light energy from the Sun powers most living systems

- **Autotrophs** produce their own food from the Sun's energy
- **Photosynthesis** = turning light energy from the Sun into chemical energy

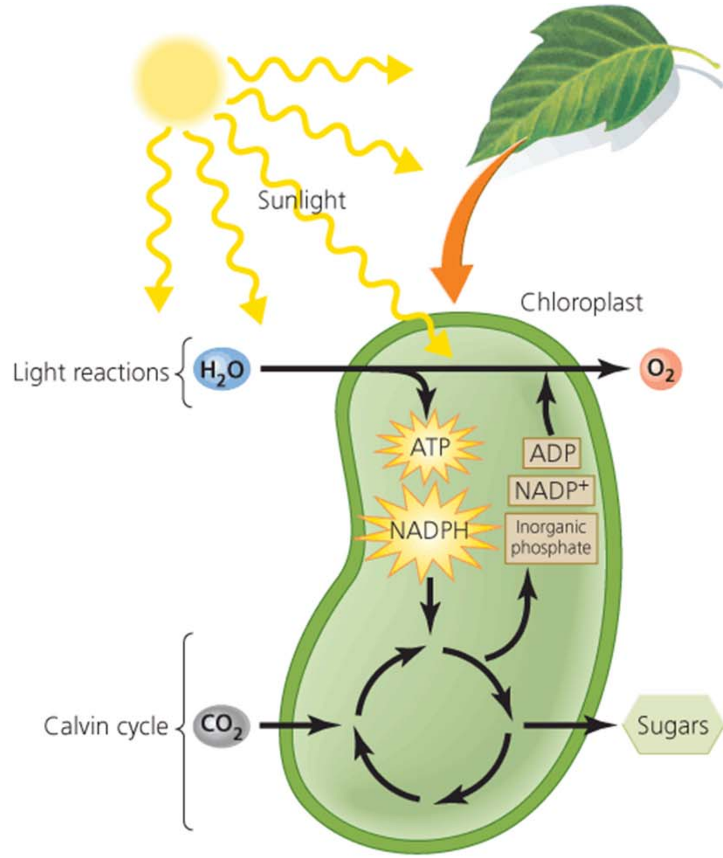

FIGURE 2.10
In photosynthesis, autotrophs such as plants, algae, and cyanobacteria use sunlight to convert carbon dioxide and water into sugars and oxygen. This diagram summarizes the complex sets of chemical reactions involved. In the light reactions, water is converted to oxygen in the presence of sunlight, creating high-energy molecules (ATP and NADPH). These help drive reactions in the Calvin cycle, in which carbon dioxide is used to produce sugars.

Light energy from the Sun powers most living systems

- **Chloroplasts** = organelles where photosynthesis occurs
  - Contain **chlorophyll** = a light-absorbing pigment
  - **Light reaction** = splits water by using solar energy
  - **Calvin cycle** = links carbon atoms from carbon dioxide into sugar (glucose)

Photosynthesis:

$6CO_2 + 6H_20 + \text{the Sun's energy} \longrightarrow C_6H_{12}O_6 + 6O_2$

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Light energy from the Sun powers most living systems

- Organisms use chemical energy from photosynthesis
- Oxygen is used to convert glucose into water + carbon dioxide + energy
- **Heterotrophs** = organisms that gain energy by feeding on others
  - Animals, fungi, microbes

Cellular respiration:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_20 + energy$$

FIGURE 2.11
When an animal such as this deer eats the leaves of a plant, it consumes the sugars the plant produced through photosynthesis and gains energy from those sugars.

Geothermal energy also powers Earth's systems

FIGURE 2.12
These thermal pools at Rabbitkettle Hot Springs in Nahanni National Park Reserve, Northwest Territories, are heated year-round by geothermal energy from deep below the ground. The bright colours on the rocks are colonies of bacteria that thrive in the hot, mineral-laden water.

Heat that emanates from Earth's interior

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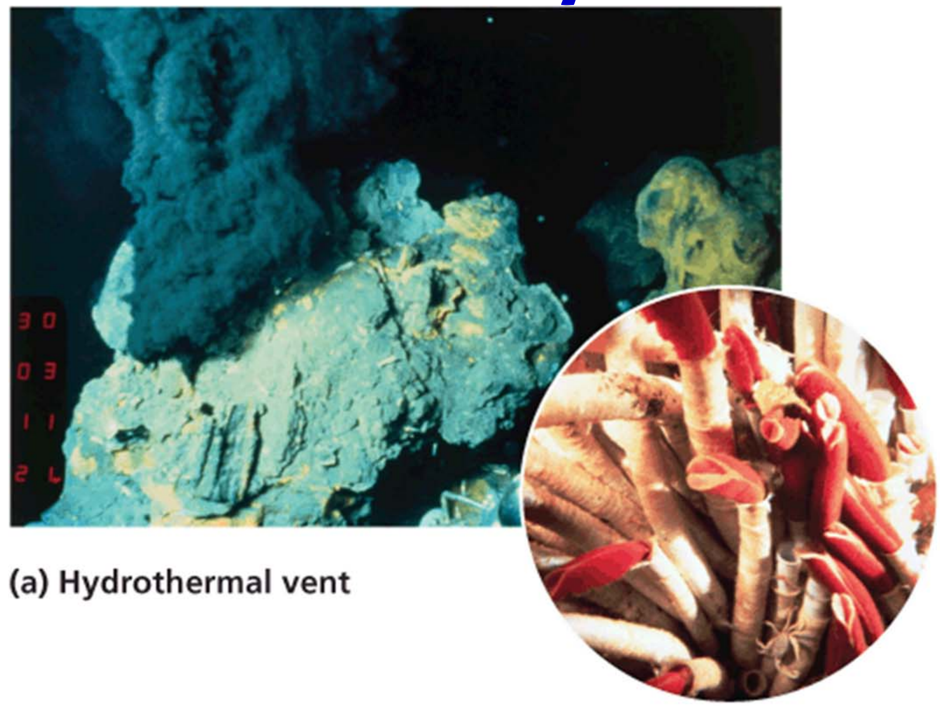
Geothermal energy powers Earth's systems

- **Hydrothermal vents** = host entire communities that thrive in high temperature and pressure on the ocean floor
  - **Chemosynthesis** = uses chemical bond energy to produce sugar



(a) Hydrothermal vent

(b) Giant tubeworms

FIGURE 2.13
Hydrothermal vents on the ocean floor **(a)** send spouts of hot, mineral-rich water into the cold blackness of the deep sea. Specialized biological communities thrive in these unusual conditions. Odd creatures such as these giant tubeworms **(b)** survive thanks to bacteria that produce food from hydrogen sulphide by the process of chemosynthesis.

$$6CO_2 + 6H_20 + 3H_2S \longrightarrow C_6H_{12}O_6 \text{ (sugar)} + 3H_2SO_4$$

Geological Systems: The Physical Basis for the Environment

- Earth consists of layers
  - **Core**: the planet's center, consisting mostly of iron, solid in the inner core and molten in the outer core
  - **Mantle**: surrounds the core, thick layer of rock
    - Asthenosphere
    - Lithosphere (upper most mantle and crust)
  - **Crust**: Thin, brittle, low-density layer of rock that covers the Earth's surface

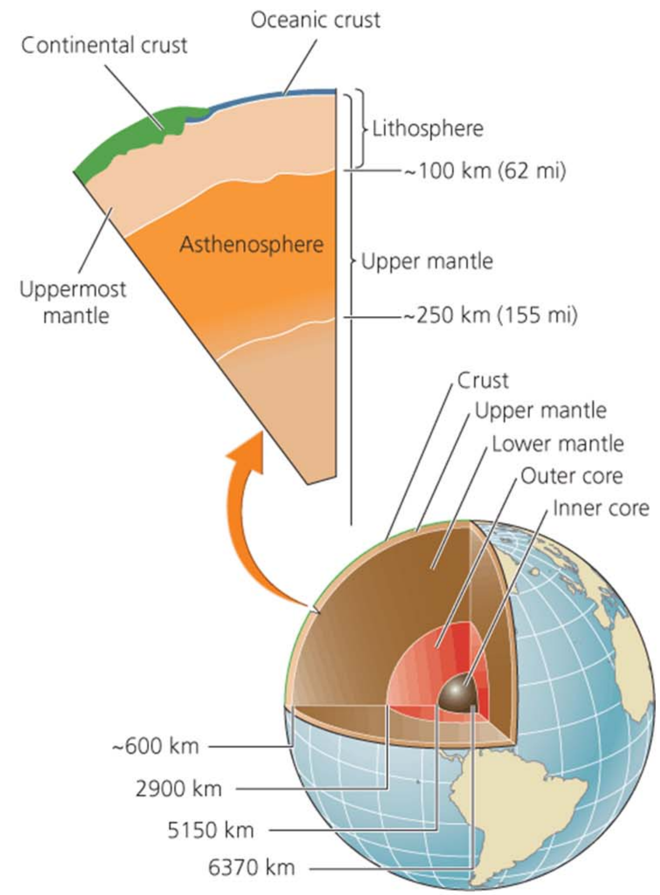


FIGURE 2.14
Earth's three primary layers—core, mantle, and crust—are themselves layered. The inner core of solid iron is surrounded by an outer core of molten iron. The rocky mantle has several layers (not shown here), including the relatively soft asthenosphere in the upper part. The lithosphere consists of the uppermost mantle (above the asthenosphere) and the crust. The crust is of two major types: dense, thin oceanic crust; and less-dense, thicker continental crust.

Plate tectonics shapes the geography of oceans and continents

- **Plate tectonics**: movement of lithospheric plates
- Fifteen major tectonic plates

World map of tectonic plates

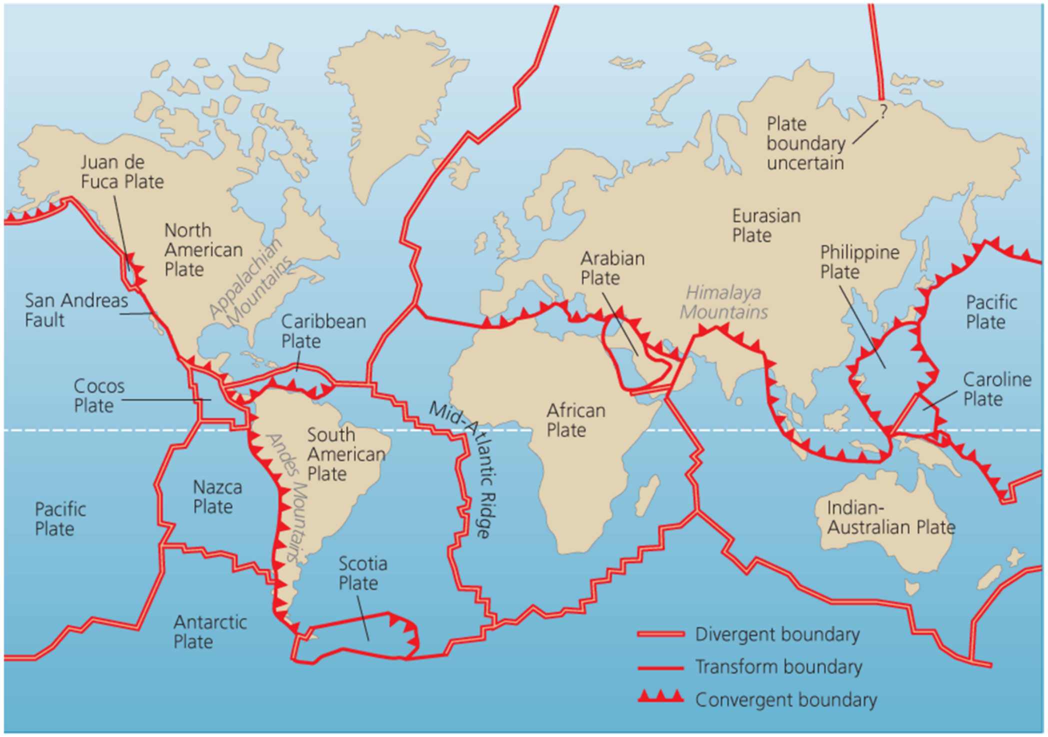


FIGURE 2.15 Earth's lithosphere has broken into approximately 15 major plates (shown here) and a number of minor plates that all move very slowly relative to one another, as part of the process of plate tectonics.

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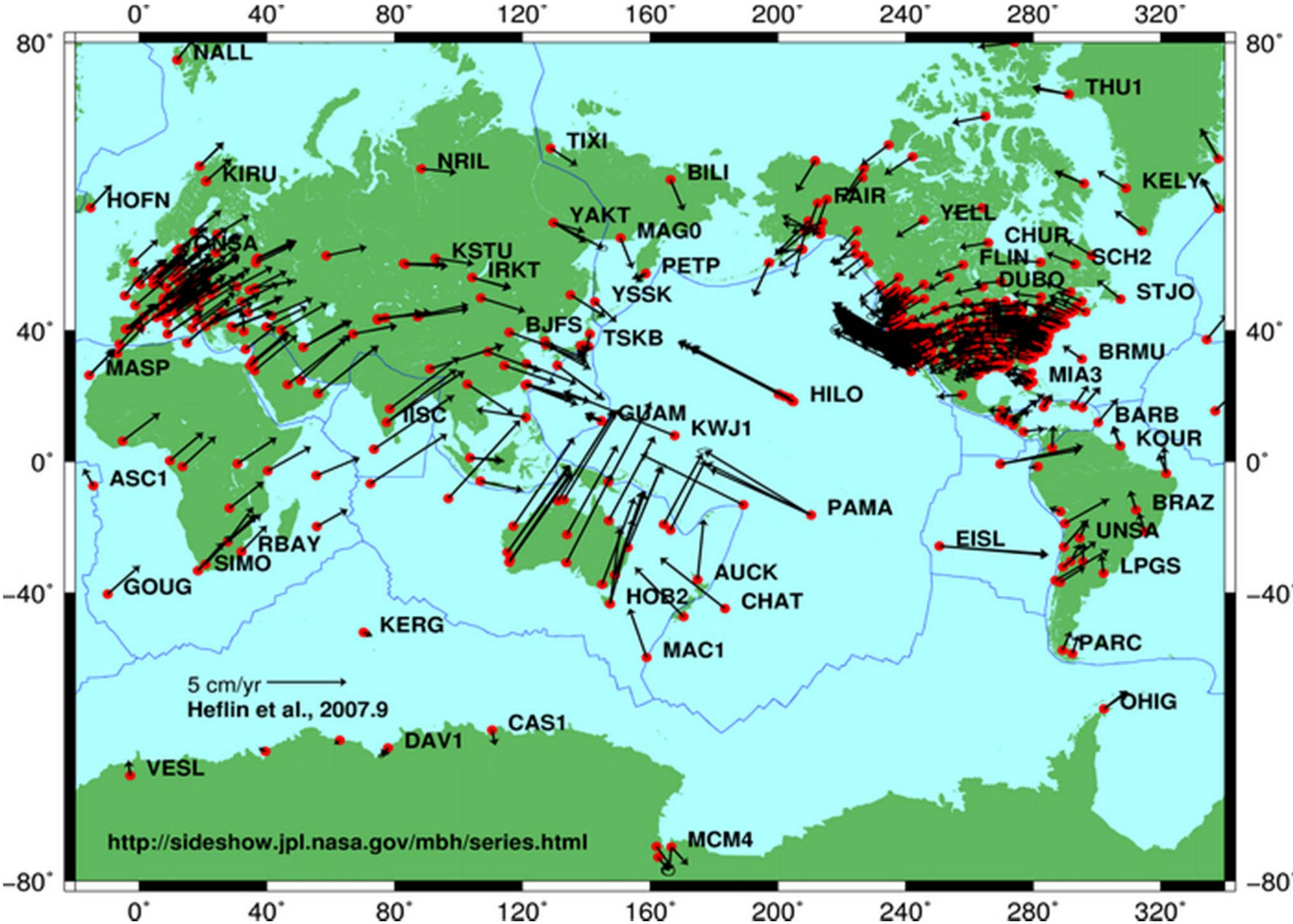
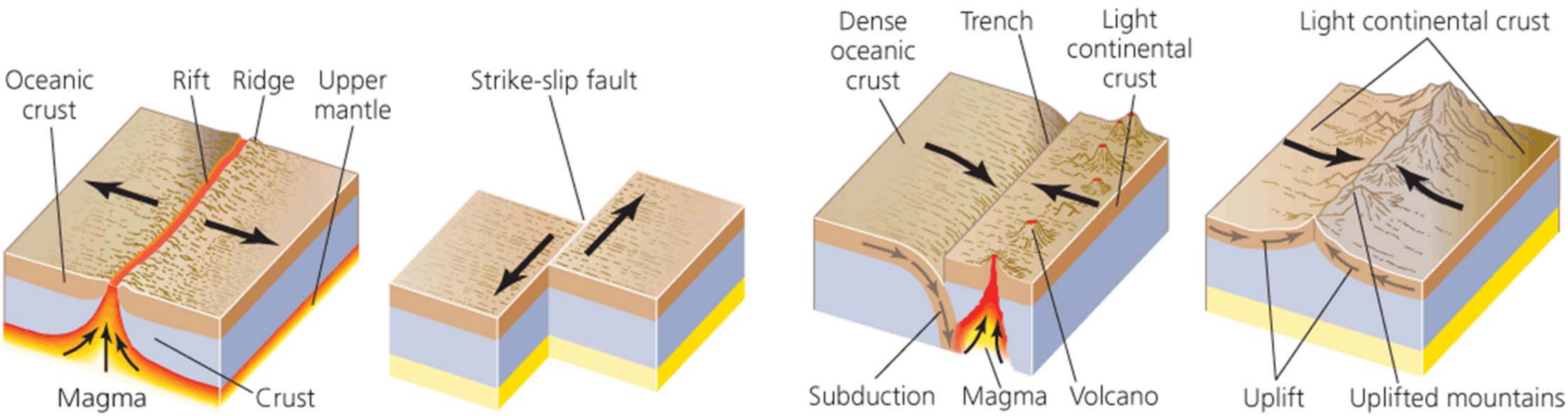


Plate motion based on Global Positioning System (GPS) satellite data from NASA JPL. The vectors show direction and magnitude of motion.
http://en.wikipedia.org/wiki/Plate_tectonics

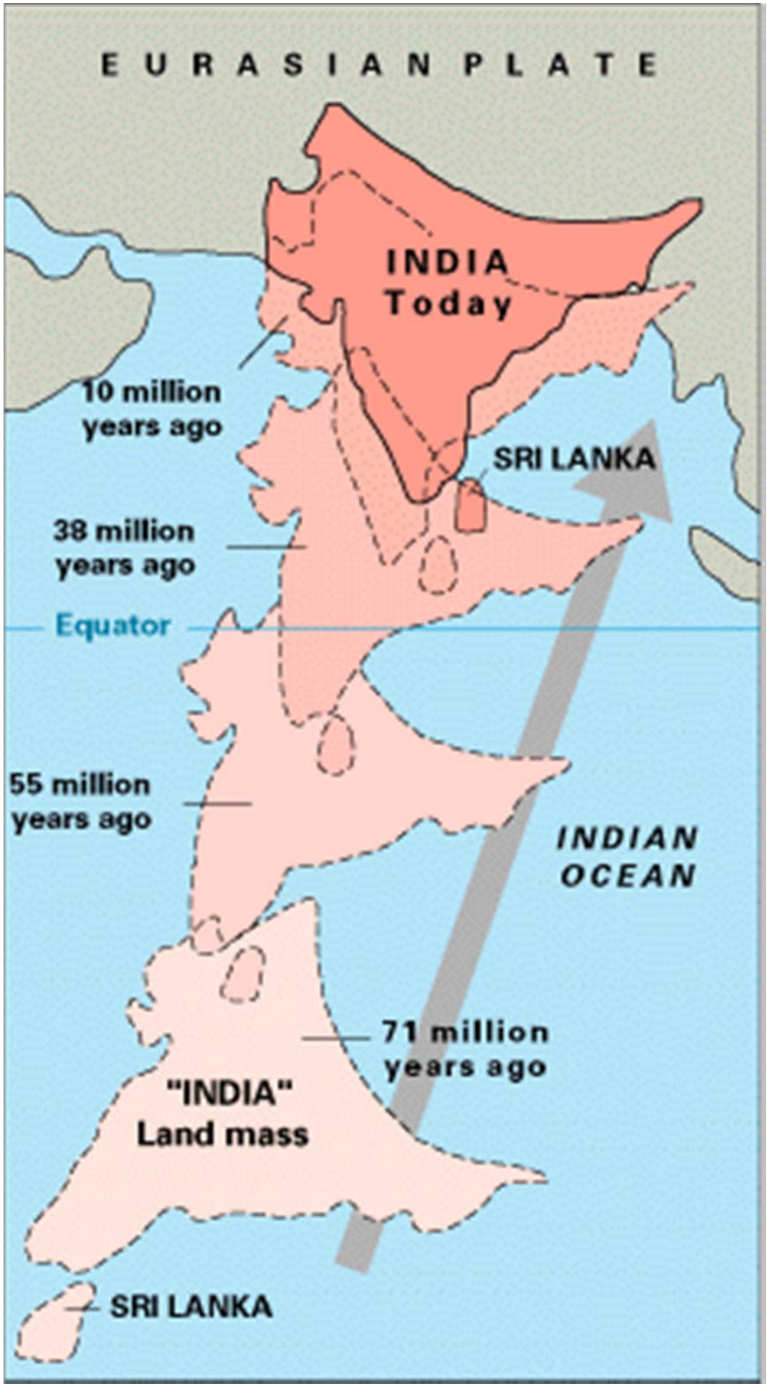
There are three main types of plate boundaries

- **Divergent**: move apart from one another
- **Transform**: horizontal in opposite directions
- **Convergent**: two plates come together



(a) Divergent plate boundary **(b) Transform plate boundary** **(c) Convergent plate boundary**

FIGURE 2.16 There are three basic types of plate boundaries: divergent, transform, and convergent. At a divergent boundary, such as a mid-ocean ridge **(a)**, magma extrudes from beneath the crust, and the two plates move gradually away from the boundary in the manner of a conveyor belt. At a transform plate boundary **(b)**, two plates slide alongside each other, creating friction that leads to earthquakes. Where plates collide at a convergent plate boundary **(c)**, one plate may be subducted beneath another (if oceanic plates are involved), leading to volcanism; or both plates may be uplifted (if continental plates are involved), causing mountain ranges to form.



http://en.wikipedia.org/wiki/Himalayas

Plate tectonics also leads to geological hazards

- **Earthquakes – relieves build-up pressure**
- **Volcanic eruptions**
  - "Ring of Fire"
- **Landslides**
- **Tsunamis**

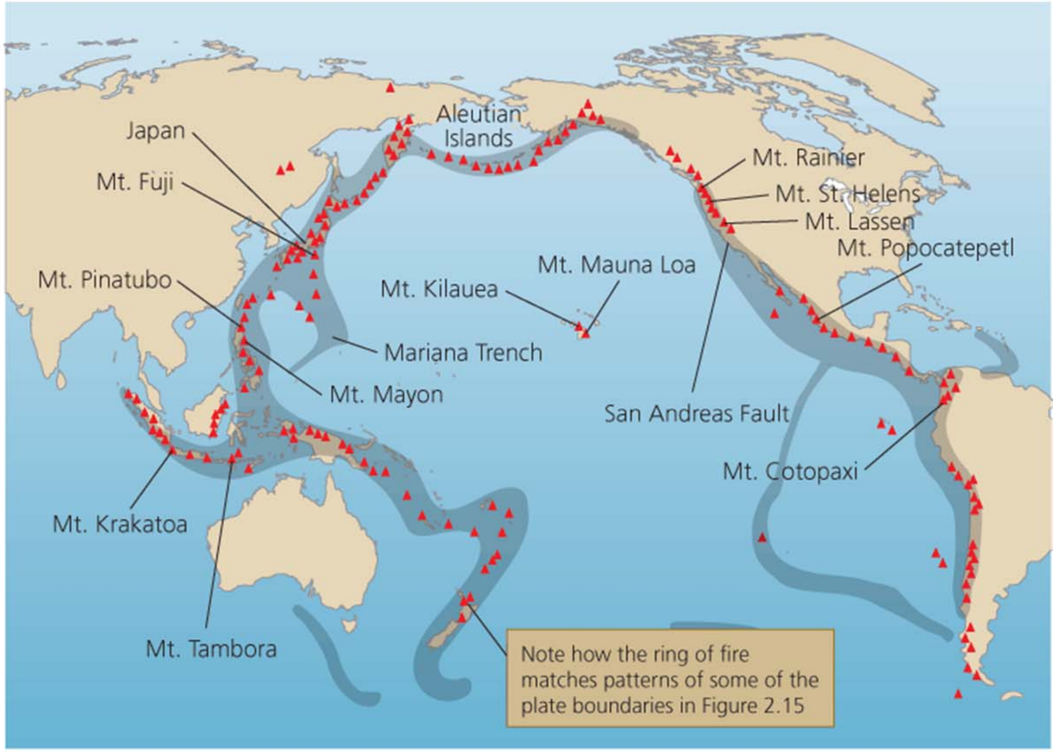
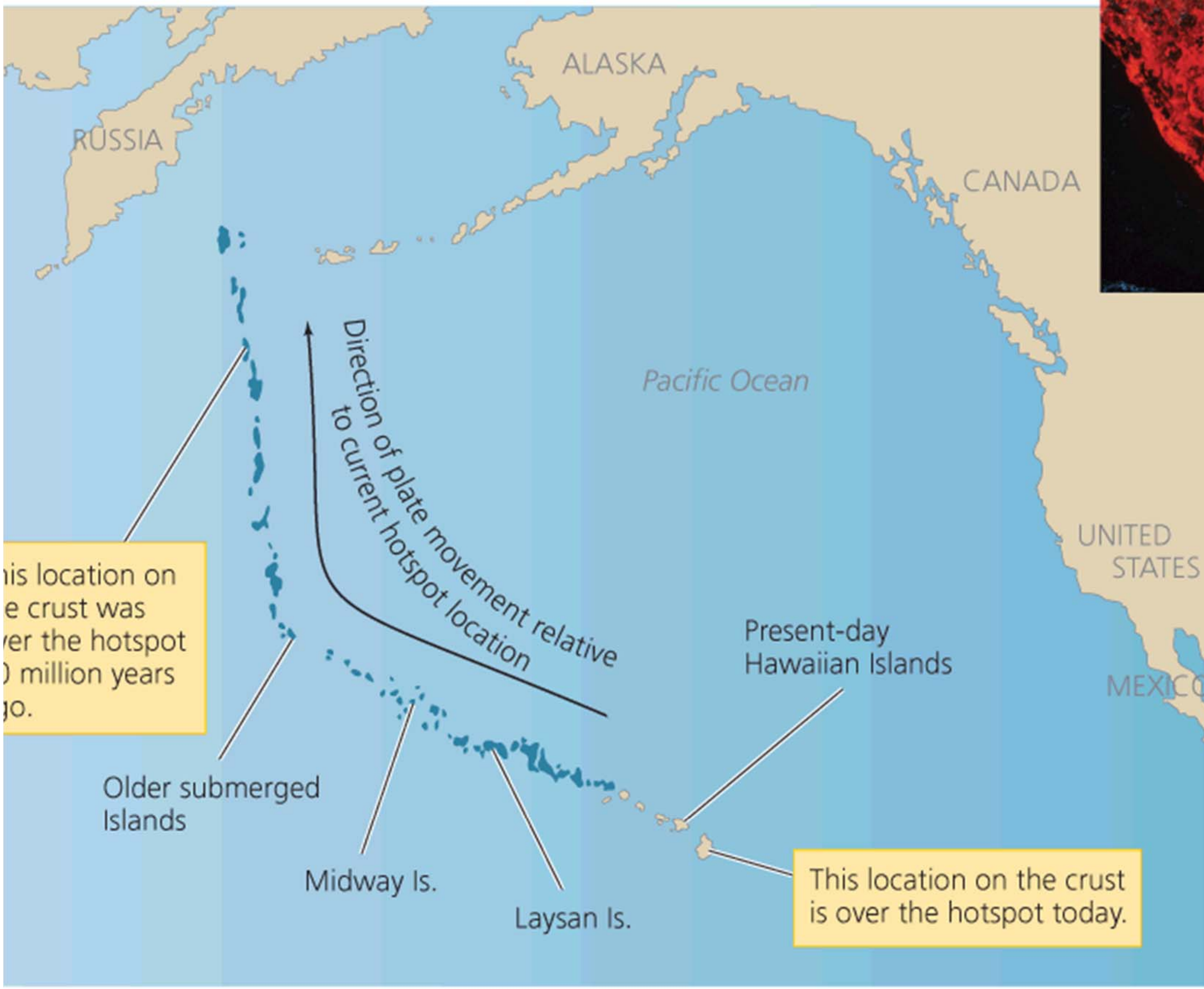


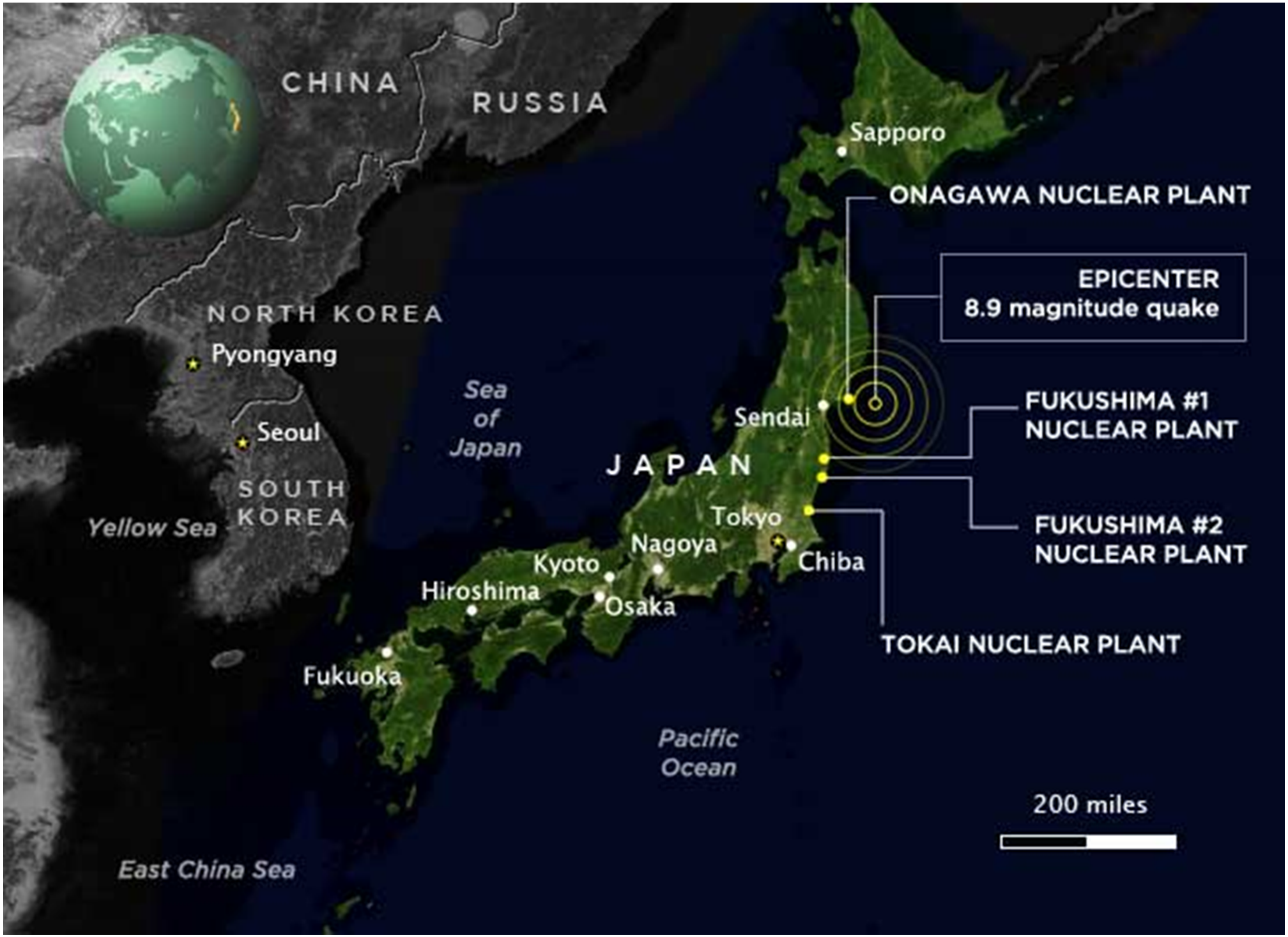
FIGURE 2.17 Many of our planet's earthquakes and volcanic eruptions occur along the circum-Pacific "ring of fire," the system of subduction zones and other plate boundaries that encircles the Pacific Ocean. The red symbols indicate major active volcanoes, and the grey shading indicates earthquake-prone areas. Compare the distribution of these hazards with the plate boundaries shown in **FIGURE 2.15**.



urrent and former Hawaiian islands, formed as crust moves over a volcanic hotspot

(b) Kilauea erupting

FIGURE 2.19
The Hawaiian Islands **(a)** have formed by repeated eruptions a hotspot of magma in the ma as the Pacific Plate passes over hotspot. The Big Island of Haw most recently formed, and it is volcanically active. The other is are older and have already beg erode. To their northwest stre a long series of former islands, submerged. In the future, the r forming volcano Loihi will one rise above the sea to form a n island to the southeast of Haw Active volcano Kilauea **(b)**, on the Big Island's southeast coast currently located above the ec of the hotspot.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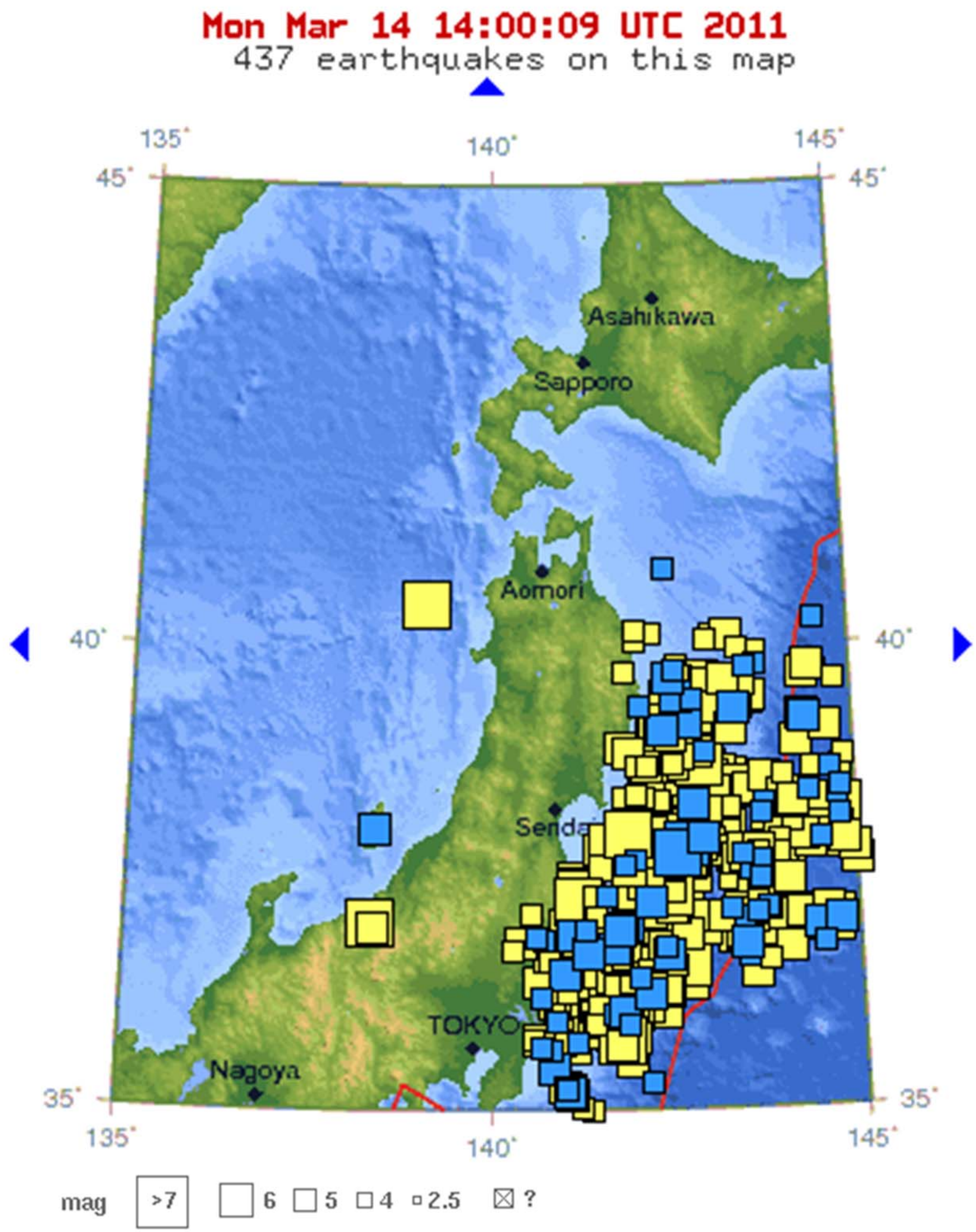
RUSSIA
Sapporo
ONAGAWA NUCLEAR PLANT
EPICENTER
8.9 magnitude quake
NORTH KOREA
Pyongyang
Sea
of
Japan
Seoul
Sendai
FUKUSHIMA #1
NUCLEAR PLANT
JAPAN
SOUTH
KOREA
Yellow Sea
Tokyo
FUKUSHIMA #2
NUCLEAR PLANT
Nagoya
Chiba
Kyoto
Hiroshima
Osaka
TOKAI NUCLEAR PLANT
Fukuoka
Pacific
Ocean
200 miles
East China Sea



http://earthquake.usgs.gov/earthquakes/recenteqsww/Maps/10/140_40.php

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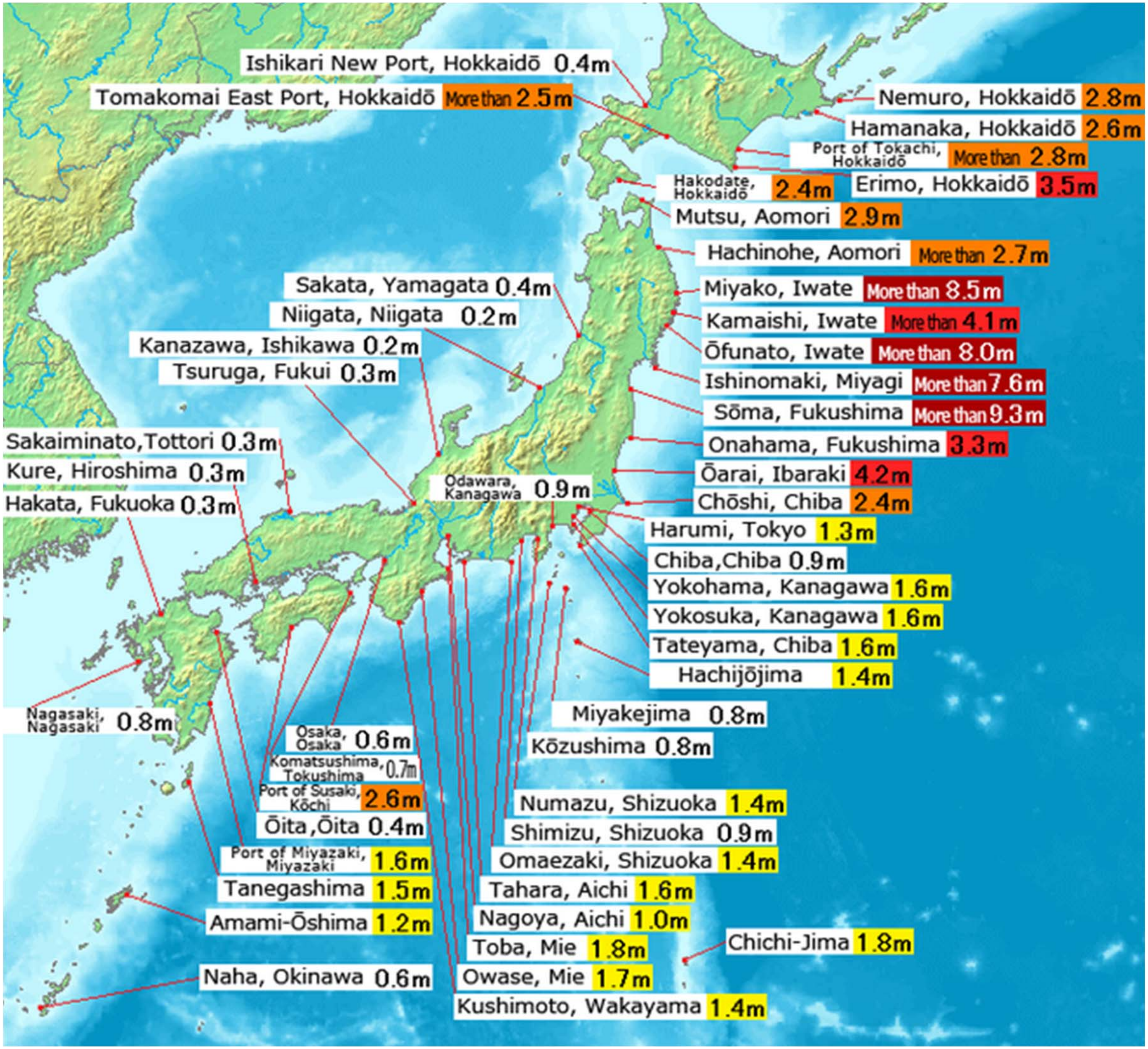
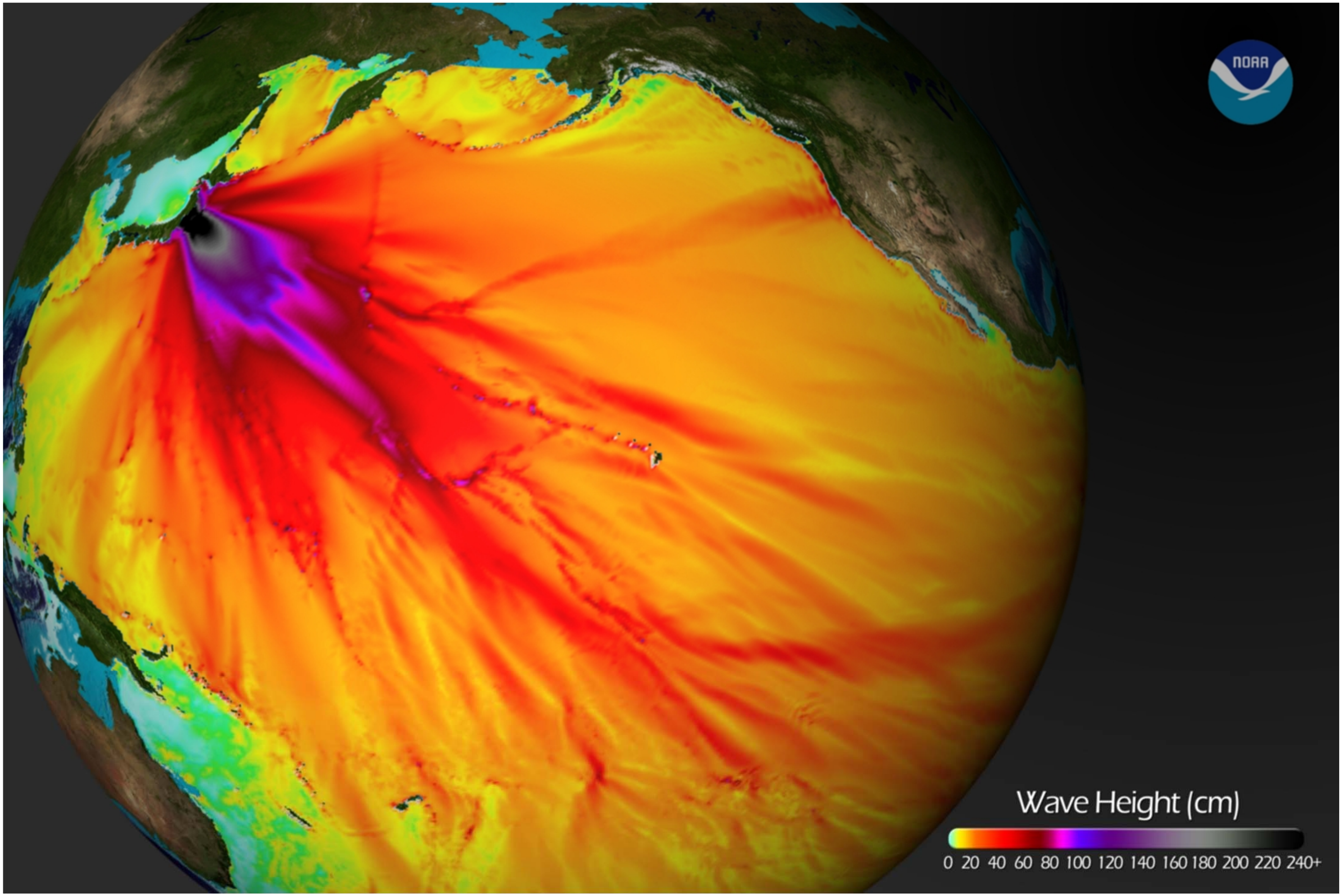


Ishikari New Port, Hokkaidō 0.4m
Tomakomai East Port, Hokkaidō More than 2.5m
Nemuro, Hokkaidō 2.8m
Hamanaka, Hokkaidō 2.6m
Port of Tokachi, Hokkaidō More than 2.8m
Hakodate, Hokkaidō 2.4m
Erimo, Hokkaidō 3.5m
Mutsu, Aomori 2.9m
Hachinohe, Aomori More than 2.7m
Sakata, Yamagata 0.4m
Miyako, Iwate More than 8.5m
Niigata, Niigata 0.2m
Kamaishi, Iwate More than 4.1m
Kanazawa, Ishikawa 0.2m
Ōfunato, Iwate More than 8.0m
Tsuruga, Fukui 0.3m
Ishinomaki, Miyagi More than 7.6m
Sōma, Fukushima More than 9.3m
Sakaiminato,Tottori 0.3m
Onahama, Fukushima 3.3m
Kure, Hiroshima 0.3m
Ōarai, Ibaraki 4.2m
Odawara, Kanagawa 0.9m
Hakata, Fukuoka 0.3m
Chōshi, Chiba 2.4m
Harumi, Tokyo 1.3m
Chiba,Chiba 0.9m
Yokohama, Kanagawa 1.6m
Yokosuka, Kanagawa 1.6m
Tateyama, Chiba 1.6m
Hachijōjima 1.4m
Miyakejima 0.8m
Nagasaki, Nagasaki 0.8m
Osaka, Osaka 0.6m
Kōzushima 0.8m
Komatsushima, Tokushima 0.7m
Port of Susaki, Kōchi 2.6m
Numazu, Shizuoka 1.4m
Ōita,Ōita 0.4m
Shimizu, Shizuoka 0.9m
Port of Miyazaki, Miyazaki 1.6m
Omaezaki, Shizuoka 1.4m
Tanegashima 1.5m
Tahara, Aichi 1.6m
Amami-Ōshima 1.2m
Nagoya, Aichi 1.0m
Toba, Mie 1.8m
Chichi-Jima 1.8m
Naha, Okinawa 0.6m
Owase, Mie 1.7m
Kushimoto, Wakayama 1.4m


NOAA
Wave Height (cm)
0 20 40 60 80 100 120 140 160 180 200 220 240+

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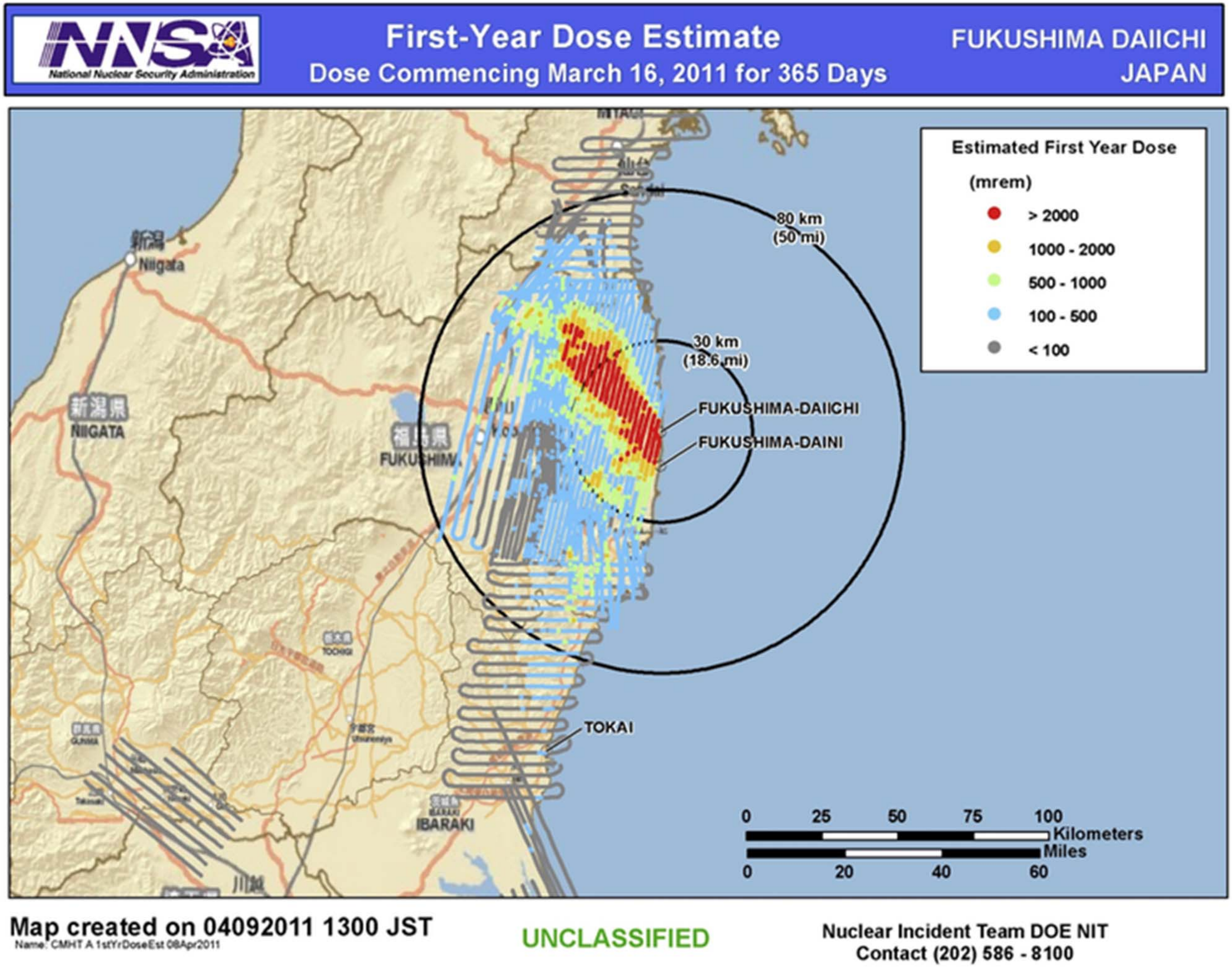
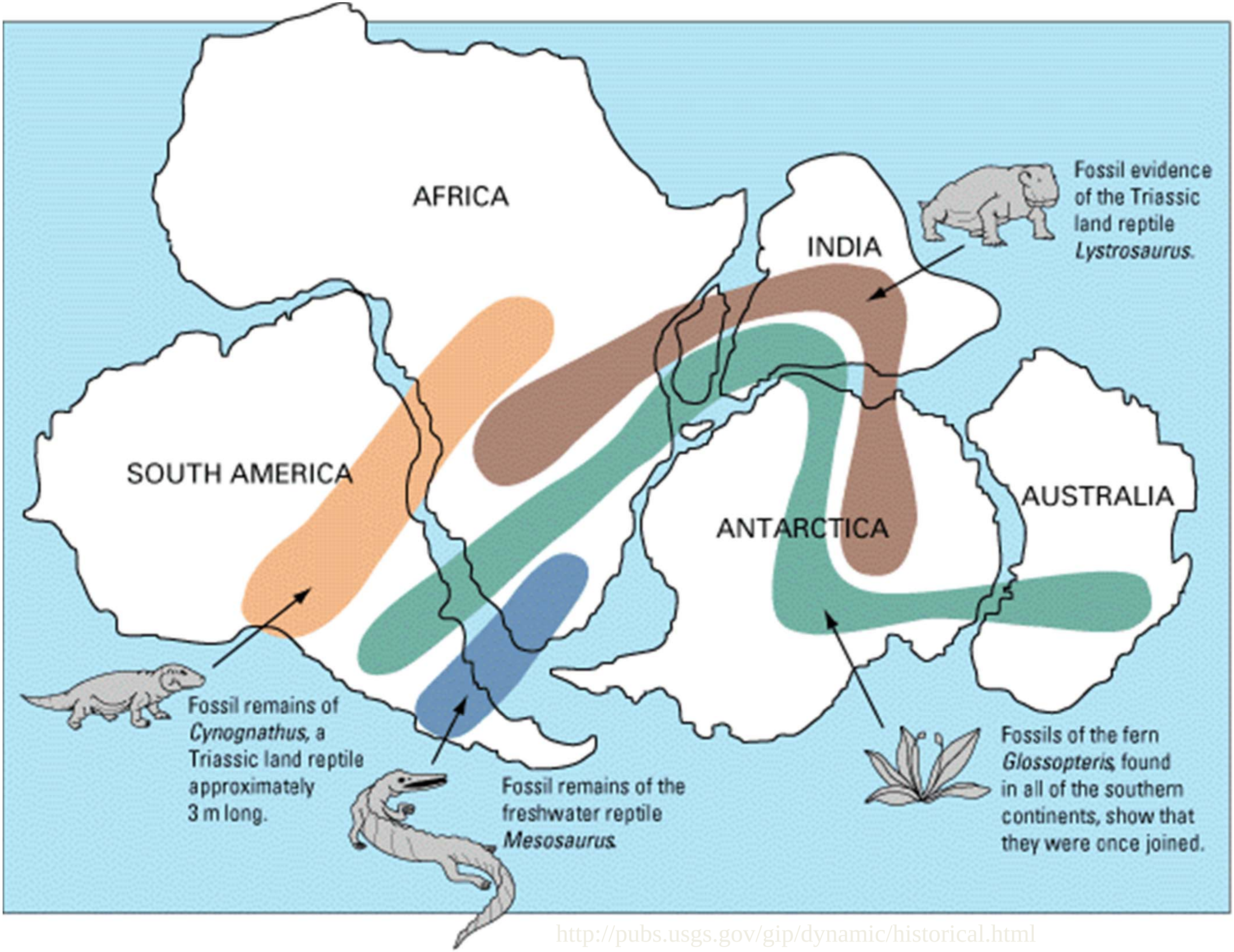


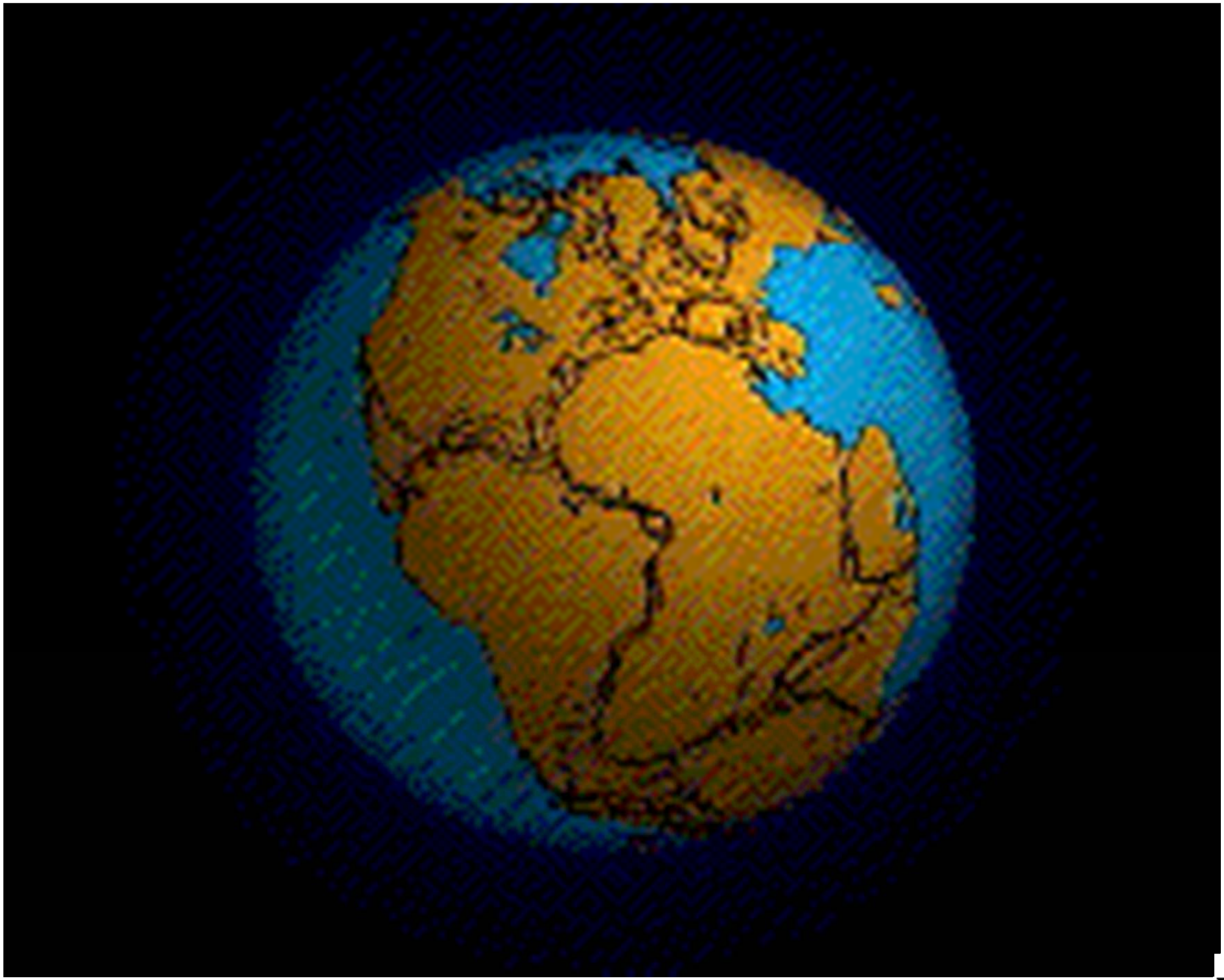
http://commons.wikimedia.org/wiki/File:NNSA_DOE_Dose_Map_Fukushima.png

200 million
years ago

Pangaea, the ancient supercontinent of 200 million years ago, combined all the world's continents in a single landmass.



http://pubs.usgs.gov/gip/dynamic/historical.html



http://en.wikipedia.org/wiki/File:Pangea_animation_03.gif

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The rock cycle modifies Earth's physical environment

- **Rock** – naturally occurring, solid aggregation of minerals
  - Type of rock influences region's soils and also plant community
- **Mineral** – naturally occurring solid element or inorganic compound that has a crystal structure, a specific chemical composition, and distinct physical properties
  - Building block of rocks

The rock cycle modifies Earth's physical environment

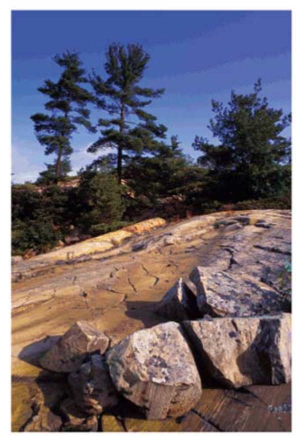
- **Igneous rock** – forms from cooling lava
  - Intrusive – granite
  - Extrusive - basalt
- **Sedimentary rock** – formed from weathering and erosion take place
  - limestone
- **Metamorphic rock** – form when rock is subjected to great heat and pressure
  - Slate and marble

(a) Intrusive igneous rock—granite

(b) Extrusive igneous rock—basalt

(c) Sedimentary rock—limestone

(d) Sedimentary rock—sandstone



(e) Metamorphic rock—gneiss

FIGURE 2.21
The Coast Range Mountains of British Columbia **(a)** are made of granite, an intrusive igneous rock. The volcanic islands of Hawaii **(b)** are built of basalt, an extrusive igneous rock. These classic cliffs in Ha Long Bay, Vietnam **(c)**, are made of the sedimentary rock limestone. These "hoodoos" in Dinosaur Provincial Park, Alberta **(d)**, are made of layered sandstone, a sedimentary rock. The Canadian Shield, which makes up the core of the North American continent, is built of very ancient metamorphic rock **(e)**, mainly gneiss.

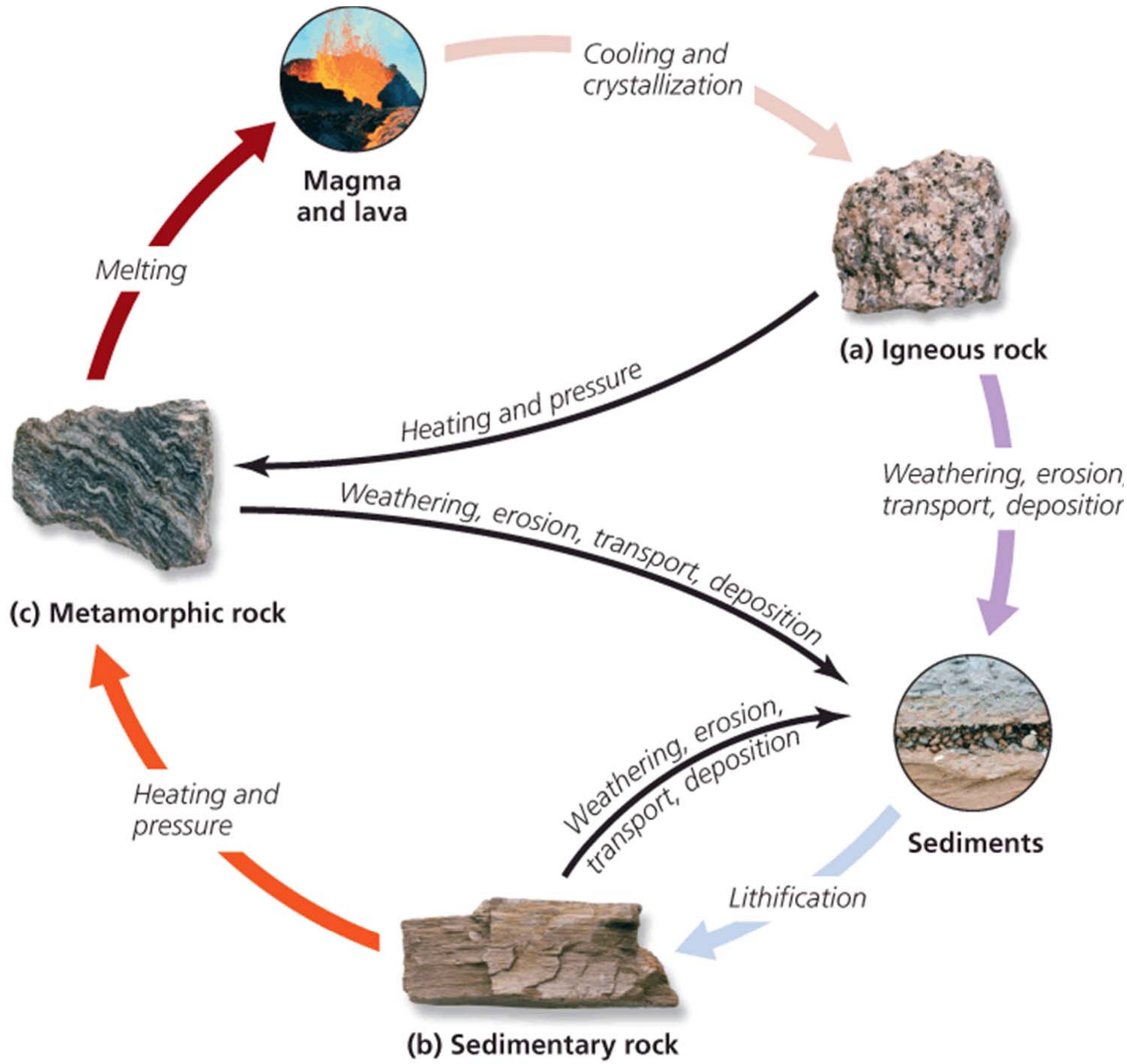


FIGURE 2.20 In the rock cycle, igneous rock **(a)** is formed when rock melts and the resulting magma or lava then cools. Sedimentary rock **(b)** is formed when rock is weathered and eroded, and the resulting sediment is compressed and cemented to form new rock. Metamorphic rock **(c)** is formed when rock is subjected to intense heat and pressure underground.

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Early Earth was a very different place

- 4.5 billion years ago, Earth was a hostile place
  - Severe volcanic and tectonic activity
  - Intense ultraviolet energy from the sun
  - No oxygen existed in the atmosphere, until photosynthesis developed in microbes
  - No life existed

FIGURE 2.22 The young Earth was a very different place from our planet today. Microbial life first evolved amid sulphur-spewing volcanoes, intense ultraviolet radiation, frequent extraterrestrial impacts, and an atmosphere containing ammonia.

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Several hypotheses explain life's origin

- **Primordial soup (the heterotrophic hypothesis)** = life originated from a "primordial soup" of simple inorganic chemicals in the oceans
  - First life forms used organic compounds for energy
- **"Seeds" from space (the panspermia hypothesis)** = microbes from space traveled on meteorites to Earth
- **Life from the depths (the chemoautotrophic hypothesis)** = life originated in deep-sea hydrothermal vents, with abundant sulfur
  - First organisms were chemoautotrophs

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Summary

- The chemical basis of matter, the nature of energy, and the geological processes that have shaped our planet provide the physical foundations for our present-day environment and support the existence of life.
- An understanding of the characteristics and interactions of matter can provide tools for finding solutions to environmental problems.
- An understanding of energy is of fundamental scientific importance as well as considerable practical relevance.

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Summary

- Physical processes of geology are centrally important because they shape Earth's terrain and form the foundations for living systems.
- Understanding how life originated enhances our understanding of how present-day organisms interact with one another, and how they relate to their nonliving environment, and how environmental systems function.

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