Core Knowledge
Earth Science
Syllabus

Introduction

Earth Science is an important and useful science for elementary-school students to study for several reasons. First, earth science is an extremely exciting and interesting field of study because its materials and processes are all around us every minute of every day of the year. No matter where students live, they are directly affected by the weather in obvious ways. Although it may be less obvious, they are also directly affected by geological history and processes and oceanographic phenomena. The nature of the landscape all around them has been determined by the geological past and is undergoing constant change. Erosion by water and wind, changes in sea level, eruption of volcanoes, and the spectacular effects produced by earthquakes appear in news reports every day. Second, students are fascinated by earth science topics like dinosaurs, meteorite impacts, black holes, comets, hurricanes, tornadoes, and volcanoes, and this fascination can be used as a way of getting and keeping them interested. And third, human society is facing many crucial environmental problems, such as global warming, water pollution, and ozone-layer depletion, whose solution lies in understanding of Earth processes, and the more people who understand the problems, the more likely we will be able to deal with them effectively.

The coverage of earth-science topics in this syllabus was determined by the topics specified in the *Core Knowledge Sequence Content Guidelines for Grade K - 8* (1999 ed.; copies available online at www.coreknowledge.org). The philosophy underlying the Core Knowledge approach is as follows.

> The Core Knowledge Sequence is a detailed outline of specific content to be taught in language arts, history, geography, mathematics, science, and the fine arts. As the core of a school's curriculum, it can provide a solid, coherent foundation of learning, while allowing flexibility to meet local needs.
>
> The Sequence represents a first and ongoing attempt to state specifically a core of shared knowledge that children should learn in American schools. It should be emphasized that the Core Knowledge Sequence is not a list of facts to be memorized. Rather, it is a guide to coherent content from grade to grade, designed to encourage steady academic progress as children build their knowledge and skills from one year to the next.
>
> The Core Knowledge Sequence is distinguished by its specificity. While most state or district curricula provide general guidelines concerning skills, they typically offer little help in deciding specific content. The specific content in the Sequence provides a solid foundation on which to build skills instruction. Moreover, because the Sequence offers a coherent plan that builds year by year, it helps prevent the many repetitions and gaps in

> instruction that can result from vague curricular guidelines (for example, repeated units on “Pioneer Days” or “Saving the Rain Forest”; or inadequate attention to the Bill of Rights, or to adding fractions with unlike denominators, or to African geography. (p. 1)

This syllabus specifies the sequence and content for a semester-long college-level course covering the rudiments of geology, meteorology, astronomy, and oceanography. The course is intended to prepare teachers to present the earth-science material to elementary-school students in grades K-8, especially, but not exclusively, in schools using the Core Knowledge curriculum.

The textbook recommended for this course is:

> Tarbuck, E.J., and Lutgens, F.K., 2000, *Earth Science* (Ninth Edition): New York, Prentice Hall, 672 pp.

Tarbuck and Lutgens is a beautifully illustrated book that is into its ninth edition, so most of the errors and problems of coverage have been eliminated. The following textbook could also be used, but its coverage of some important topics is not as complete.

> Skinner, B.J., and Porter, S.C., 1995, *The Blue Planet*: New York, John Wiley & Sons, 493 pp. + apps.

The syllabus includes material for a three-hour laboratory each week in which students are introduced to various materials, data, and instruments. The laboratory manual recommended is:

> Tarbuck, E.J., Lutgens, F.K., and Pinzke, K.G., *Applications & Investigations in Earth Science* (third edition): Upper Saddle River, NJ, 353 pp.

The syllabus includes sample mid-term and final exams, but laboratory exams are not provided. It is anticipated that the lab exams would be very practical and based on the exercises completed during the semester. For example, it is recommended that one substantial aspect of the final laboratory exam be a test of mineral and rock identification in which students are expected to identify without the aid of written material the minerals and rocks specified in the syllabus.

This syllabus was created by James H. Shea, Emeritus Professor of Geology at the University of Wisconsin-Parkside and longtime editor of The Journal of Geoscience Education, as part of What Elementary Teachers Need to Know, a teacher education initiative developed by the Core Knowledge Foundation. Although the syllabus is copyrighted by the foundation, and may not be marketed by third parties, anyone who wishes to use, reproduce, or adapt it for educational purposes is welcome to do so. However, we do ask individuals using this syllabus to notify us so we can assess the distribution and spread of the syllabi and serve as a repository of information about how they may be improved and more effectively used. Please contact us at http://coreknowledge.org/CK/contact.htm.

WEEK 1

Reading: Chapters 14 & 15 in Tarbuck & Lutgens

Students should know that:

The Earth is very nearly a sphere with a diameter of very roughly 8,000 miles. The outermost shell of this sphere is a gaseous atmosphere about 100 miles deep. The bulk of the Earth is solid and rocky. Resting on top of the rock is a large amount of water, so much that it covers about 75 percent of the surface to an average depth of over two miles. The rocky part of the Earth is layered also. On the outside is a thin crust composed of rock, weathered rock, and soil. Beneath the crust, there is a rocky shell called the mantle, which is about 1700 miles thick. Beneath the mantle Earth has a central core that is "liquid" in its outer, solid in its inner part. Our study of the Earth will begin with the atmosphere.
(See fig. 1.5 in Tarbuck and Lutgens)

Meteorology

The atmosphere and solar radiation

Students should know that:

1. The character and amount of the Sun's energy output are directly controlled by its surface temperature and its surface area. Because the Sun is hot (It has a surface temperature of about 6,000 K.) and because it is so large (Its surface area is roughly 12,000 times that of Earth.) It puts out an immense amount of energy, only a tiny part of which falls on Earth because Earth is so far from the Sun. A substantial fraction of what does strike Earth (a little less than 40%) is reflected back into space. Because of its surface temperature, the peak of the Sun's radiation curve occurs in the visible region of the electromagnetic spectrum. This is crucial to Earth's environment.

2. Earth's atmosphere is largely transparent to radiation in the visible part of the spectrum, so what isn't reflected passes through the atmosphere and reaches the surface, which it heats. However, Earth's surface is obviously not as hot as that of the Sun, so it radiates at longer wavelengths, specifically in the infrared, and this radiation does not pass as freely through the atmosphere. Some of it is absorbed by various constituents of the atmosphere, notably water vapor, carbon dioxide, and methane, which are called "greenhouse gases." Earth's atmosphere is, therefore, heated from below, a fact which is of crucial importance in creating a suitable environment for life at the surface and causing the vertical circulation of the atmosphere, which is a crucial element in our weather.

3. Because Earth is basically a sphere, and because its axis of rotation is tilted 23.5 degrees from being perpendicular to the plane of its revolution around the Sun, Earth's surface is unequally heated by the Sun. At any given moment, half of the Earth faces away from the Sun and receives no energy. Also at any given moment, regions away from the equator receive progressively less radiation, so polar regions are generally

cooler. The tilt of the axis, which changes only very slowly, and Earth's revolution around the Sun result in the northern and southern hemispheres alternately being tilted toward the Sun, which gives Earth its seasons.

4. Earth's atmosphere decreases progressively in density from the surface to high altitudes in such a way that at a height of about 100 miles it's density is only about a billionth of its density at sea level. Even somewhat above that level the atmosphere is substantial enough that artificial satellites orbiting at 150 miles are slowed by friction with the atmosphere and eventually fall to Earth. For many purposes though, we can think of the atmosphere is being about 100 miles deep. This sounds like a lot, but if we consider a model of the Earth with a diameter of one foot, the atmosphere would be less than one-eighth of an inch thick. Thus the atmosphere constitutes only a very thin film around the Earth.

5. Because air has weight, it presses down on Earth's surface and everything on it, including us. We call this effect "pressure," specifically air pressure. At higher elevations there is less air above so the pressure is lower. At 3.4 miles air pressure is half what it is at sea level; at about 35 miles, air pressure is only about a thousandth what it is at sea level.

Laboratory - Gathering and interpreting weather data

The purpose of this lab is to get students to thinking actively and specifically about the seasonal and long-term progression of weather in their area and to give them experience in looking up data, transcribing it to a computer spreadsheet, processing the data, and graphing it.

Each student should be given a specific assignment as to which weather data (that is, which dates he or she is responsible for obtaining), and where the data should be obtained. The data can be obtained from the local newspaper or from the Web. The three quantities the students should work with are the daily high temperature, the daily low, and the amount of precipitation. The daily mean temperature is the average of the high and low for each day.

The specific goal is to obtain as long a weather record as possible, to prepare a graph of the daily mean temperature for the period involved, and to determine whether the graph shows any long-term trends or cycles.

It may be necessary to prepare sheets for recording the data. Such pages should have a place to record the location, the month and year at the top of the page, a column of numbers from one to 31 running down the page (the day of the month), and blank spaces for recording the daily high, low, and precipitation. The students can then use these sheets as a source for the data to be keyed into the spreadsheet where a daily mean temperature will be calculated. They can also use the data for calculating a yearly average temperature and a graph showing how the average temperature has varied from year to year.

This exercise should be run as a semester-long project. At the end, the students should have prepared a graph of the yearly average temperature over the period for which data are available. In many cases, the record available will be over 100 years long and will reach back into the late 19th century (but not much further).

WEEK 2

Meteorology

Reading: Chapters 16 & 17 in Tarbuck and Lutgens

Students should know that:

1. The atmosphere consists almost entirely of two gases: 78% nitrogen and 21% oxygen. The other gases (notably water vapor, carbon dioxide, and argon), even though they occur in only trace amounts are very important in determining Earth's surface temperature.

2. The atmosphere consists of four shells (or "spheres") based on the temperature gradient.

a. The "troposphere," which extends from the surface up to about 10 km, within which temperature mostly decreases with altitude. Most of what we call "weather" occurs in the troposphere, which is vertically and horizontally circulated by winds.

Vertical circulation of the atmosphere occurs by a process called "convection." When a fluid is heated locally, the fluid expands and its density decreases. As a result, a mass of low-density fluid forms. This low-density fluid then rises or "floats" upward and cooler, denser fluid flows in beneath it and is in turn heated, leading to more rising fluid. The end result of the local heating is the creation of a rising column of warmer fluid and a corresponding downward flow of fluid elsewhere. Such circulatory systems are called "convection cells," and they occur in both liquids and gases and even in slowly flowing solids, such as the Earth's outer core and mantle. Convection currents redistribute heat energy in the fluid and also tend to thoroughly mix the fluid in the layers where convection occurs.

b. The "stratosphere," which extends from the troposphere up to about 50 km in elevation, is rich in ozone, which absorbs incoming ultraviolet radiation and causes temperature in the stratosphere to increase from bottom to top. The occurrence of this "ozone layer" is of crucial importance to terrestrial life because it prevents much damaging ultraviolet radiation from reaching the surface. UV radiation can, for example produce skin cancer in humans.

c. The "mesosphere," which extends from the stratosphere up to about 80 km in elevation. Temperature decreases from bottom to top in the mesosphere.

d. The "thermosphere," which extends from the mesosphere up to an indefinite elevation. Temperature increases from the base of the thermosphere to its top and may reach 1,000 degrees C. However, air density is so low at these elevations that, if we put our hands into the thermosphere, it would not feel hot at all.

“Temperature” is a measure of the average kinetic energy of the atoms and molecules in a mass of material. The molecules and atoms in a gas, for example, are constantly in motion, striking one another and recoiling. In the thermosphere the temperature is high because the available energy is shared by very few molecules, so their average kinetic energy, and therefore their temperature, is high.

3. Water is the most important trace gas in the atmosphere. Humidity is a measure of the amount of water vapor in the air. Students should know the difference between absolute and relative humidity.

a. Water is the most important “greenhouse gas.”

b. It forms clouds, which largely control Earth’s albedo.

c. It plays a key role in the transfer of heat and the control of Earth’s temperature by changing state (condensing and evaporating) moving from place to place.

d. It is essential to human life.

4. Clouds are one of the most important elements of weather. Clouds consist of masses of tiny water and ice droplets that form around tiny particles in the atmosphere. Rain occurs when large numbers of cloud droplets combine to form much larger raindrops, which are too large and heavy to be suspended by the atmosphere. There are many different types of clouds; they form at various levels in the atmosphere, and they tell us a great deal about weather. Students should be able to identify cumulus, cumulonimbus, altocumulus, cirrus, nimbostratus, altocumulus, and altostratus clouds.

Hail is formed when raindrops are carried to high altitudes, where air temperatures are below freezing. Sometimes this happens repeatedly, leading to the growth of very large hailstones that may be as big as baseballs. Hail can be a devastating phenomenon. It can cause considerable damage to homes, automobiles, and crops.

Snow forms when water sublimes in the form of hexagonal ice crystals, which start small and grow by the sublimation of more water. The type of snowflakes that form is determined largely by temperature. At low temperature, light, “fluffy” snowflakes form. At temperatures just below freezing, where humidity is likely to be higher, the flakes clump together, forming larger, heavier flakes.

5. Lightning is the discharge of static electricity between the Earth and its atmosphere. Thunder is the sound created when air is first intensely heated by the lightning and expanding instantly and then immediately cooling and collapsing. The distance between an observer and a flash of lightning can be gauged by the time lag between the flash of lightning and hearing the thunder it created. Lightning is a very dangerous phenomenon and frequently kills people. Any sighting of lightning in an area is a warning to get indoors immediately.

6. Air pollution involves the release of various undesirable and damaging gases and particles into the atmosphere. Some of the most abundant and important pollutants are carbon dioxide, carbon monoxide, sulfur oxides, nitrogen oxides, ozone, volatile organic compounds (VOCs), soot, and ash. The most important general sources of pollutants are transportation, power generation, industrial processes, and space heating.

One particularly troublesome type of pollution is "smog," which forms when sunlight causes volatile organic compounds (such as those that are produced by the combustion of gasoline in automobile engines) in the air to react chemically and form new compounds that are irritating to breathe and at least mildly toxic. In many cases the air over large cities is so smoggy that visibility is seriously reduced.

7. Wind is movement of air caused by differential heating, which leads to expansion of air in some places and contraction in others, producing pressure differences. The flow of air from areas of high pressure to areas of low pressure is called wind. Wind produces changes in weather by bringing in air masses with different characteristics, for example, lower or higher temperatures or higher or lower humidity.

Wind speed and direction are controlled by three factors: pressure differences, friction, and the Coriolis effect. The first two are fairly easy to understand. Obviously the greater the pressure difference, the greater the wind velocity. Also, since the air is in contact with Earth's surface and with objects on the surface, air experiences frictional resistance when it moves. Friction slows winds and changes their direction. (See Fig. 16.11)

The Coriolis effect is produced by Earth's rotation and is due to the fact that objects near the equator are moving faster due to rotation than objects nearer the poles. The net effect is that winds in the northern hemisphere are deflected toward the right, whereas winds in the southern hemisphere are deflected toward the left, and wind directions end up being parallel to lines of equal pressure (isobars). (See Fig. 16.12)

8. "Fronts" are surfaces that separate air masses of different temperature: warm fronts involve warmer air moving over areas that were formerly colder; cold fronts involve colder air moving over areas that were formerly warmer. Warm fronts typically involve warmer air moving up and over colder air, leading to precipitation as the warm air cools as it rises (see Fig. 17.5). Cold fronts tend to wedge beneath warm air causing it to rise rapidly, thereby producing strong winds and intense rainfall (see Fig. 17.7).

When air is compressed, its temperature increases because work is being done on it and energy is added. For example, when a hand pump is used to inflate a tire, the air pump becomes warm to the touch. Conversely, when air expands, it cools because it is doing work by actively pushing away surrounding gas. For example, when air that has been compressed into a storage cylinder is allowed to escape, the escape valve cools to the touch and may cause condensation to form on the valve. The compressive heating and expansive cooling of atmospheric gas are called "adiabatic" heating and cooling because heat is neither added nor subtracted from the gases.

As dry atmospheric gas parcels rise, they cool at a rate of approximately 10 deg. C for every 1000 meters of rise. This rate is called the dry adiabatic lapse rate. As dry gas parcels sink, they heat at the same rate. Air with moisture in it behaves somewhat differently. As moist air rises, it cools, eventually reaching the dew point, at which time water begins to condense and release latent heat of vaporization, which lowers the lapse rate. The wet adiabatic rate varies with the amount of moisture present; it is higher if the humidity is low and lower if the humidity is high.

The phenomenon of adiabatic cooling is used in refrigeration and air conditioning when a refrigerant gas is compressed and its heat is allowed to dissipate to the atmosphere. Then the compressed gas is moved in insulated lines to cooling coils where it is allowed to expand and cool, thereby making it possible to cool the air in a refrigerator or room air in an air conditioner.

9. Local weather is determined in part by local factors such as topography, bodies of water, and latitude. Thus, local weather varies greatly from place to place even though there are broad patterns that are controlled by larger factors, such as regional atmospheric circulation and proximity to oceans.

10. Weather maps depict the state of the atmosphere in a given area at a given time. They are based on measurements at surface stations and on satellite observations. Isotherms are lines of equal temperature; isobars are lines of equal pressure. Pressure is measured by devices called “barometers.” The first barometers used a column of mercury to measure pressure; thus pressure is often given as inches or centimeters of mercury.

11. Rainbows are seen when light is reflected and refracted by raindrops. Light of different wavelengths is refracted by different amounts, leading to the separation of the different colors present in sunlight. Rainbows are most commonly seen when the sun is in one direction from an observer and rain is falling somewhere off in the opposite direction.

Tornadoes are intense, small, local storms that consist of a rapidly rotating column of air extending downward from a thunderstorm cloud. They usually have a diameter of only a few hundred yards. Wind velocities can reach 250 miles per hour. Tornadoes cause millions of dollars of property damage and kill dozens of people each year.

Hurricanes are much larger storms that form over the oceans in tropical areas of the Atlantic, Pacific and Indian oceans and move for thousands of miles across the surface. Their winds range in velocity up to about 200 miles per hour and they can cause billions of dollars of property damage and kill many thousands of people. The damage is caused not only by the high winds but by intense rainfall, enormous waves, and by the “storm surge” of high water that is produced by the very low pressure at the center of the hurricane. A hurricane that struck Bangladesh in 1970 probably caused a half million deaths.

Laboratory

Exercise 14 in Tarbuck, Lutgens, & Pinzke: Atmospheric moisture, pressure, & wind

WEEK 3

Climate

Reading: Tarbuck & Lutgens Chapter 18

Students should know that:

1. Whereas “weather” is the condition and behavior of the atmosphere for an area at any given moment or over relatively short periods of time, “climate” is the average condition and behavior of the atmosphere for an area over longer periods of time. Climate includes the same elements as weather, particularly temperature and precipitation. One of the strongest indicators of climate is the animals and plants that live in a given area. Organisms may tolerate unfavorable conditions for some years, but if the conditions persist, they will eventually cease to live in an area. Similarly, plants or animals may move into areas that formerly had climates unfavorable to them.

2. Humans study climate and climate change in two ways: first by taking long-term averages of weather phenomena such as temperature and precipitation, and second by studying phenomena that are sensitive to long-term changes in weather such as changing flora and fauna, the advance and retreat of glaciers, and tree rings. Ancient climates are determined by phenomena that are called climate “proxies” such as sediments, the ratio of oxygen isotopes in fossil shells, and the concentration of carbon dioxide in the atmosphere as determined from gas bubbles in glacial ice and amber. The study of climate change is complicated by the fact that instrument-based weather records have only been kept for a little more than 100 years.

3. Terrestrial climates are classified into five broad types:
   - Humid tropical
   - Dry, where evaporation exceeds precipitation;
   - Humid, middle latitude with mild winters
   - Humid, middle latitude with severe winters
   - Polar

Laboratory

Exercise 17 in Tarbuck, Lutgens, & Pinzke: Astronomical observations

WEEK 4

Astronomy

Reading: Tarbuck and Lutgens Chapter 19

Students should know:

1. The different kinds of telescopes:
    - a. Optical
        - Reflecting
        - Refracting
    - b. Radio and microwave
    - c. Infrared and ultraviolet
    - d. X-ray and gamma ray

2. That the resolution of optical telescopes is controlled by:
    - a. Atmospheric “seeing,” that is the turbulence of the atmosphere
    - b. The size of the mirror or reflecting lens
    - c. The quality of the optical system
    - d. The wavelength of the light being observed

3. That increasing the size of the objective mirror of a telescope increases the amount of light brought to a focus (thus allowing dimmer and more distant objects to be seen), and also increases resolution.

4. That placing a telescope above the atmosphere solves two problems: the limitation of “seeing,” and the absorption of light of certain wavelengths (such as ultraviolet and infrared).

5. That the ancient Greeks were the first to study the stars and planets scientifically and to apply geometry, mathematics, and rational thought (as opposed to magical thought) to astronomy. They knew that the planets, our moon, and the sun are spherical, that the Earth is a planet, that planets and the moon are illuminated by sunlight, and that the sun is very far away and therefore, by inference, larger than the Earth. They worked out mechanical and mathematical models of the solar system, measured the size of the Earth, and catalogued stars based on their brightness. Their study of astronomy contributed strongly to the birth of science.

6. That the understanding the concept of gravity as stated by Isaac Newton in his “law of gravity” is crucial to understanding the behavior of astronomical bodies. Newton expressed his concept of gravity in mathematical form, the form that is customary in modern science. Mathematically, the law is:

$$F = G\,M\,m / d^2 .$$

In words, this says that the gravitational attraction between any two objects is directly proportional to the product of the masses of the two objects and inversely proportional to the square of the distance between them. Thus, if one of the masses were doubled, the attraction would also double, and if the distance between them were doubled the attraction between them would be one fourth as great.

7. That gravity plays a crucial role in:

a. Causing the aggregation of interstellar gas and dust into stars and planets.
b. Determining whether a body will be a star or a planet.
c. Controlling the orbits of bodies in motion around other bodies.
d. Determining whether a planet will be able to hold its atmosphere.
e. Determining how fast a star will evolve and in what way.

8. That Copernicus revived an old Greek theory when he proposed that the sun, not the earth, lies at the center of the solar system, and that the earth revolves around the sun in one year and rotates on its axis in one day. After Galileo proved that the theory of the earth-centered solar system is invalid, the Copernican theory was accepted, and it revolutionized our human concept of our place in cosmos. Earth could no longer seen as the center of everything; it was simply the third of six (then known) planets orbiting the sun. Since the earth was not at the center of the system, since it was not the biggest of the planets, and since the sun was simply one among many millions of stars, humans could no longer view themselves as being at the center of the universe, or as the reason for the existence of everything.

9. That Kepler's laws of planetary motion mathematically described the motions of orbiting bodies.

First law: planets move in elliptical, not circular orbits.

Second law: A line from a planet to the sun sweeps across equal areas in equal times.

Third law: The square of the period of a planet is proportional to the cube of its average distance from the sun.

Later, Newton showed that Kepler's laws can be derived from Newton's laws of motion and his law of gravitation.

10. That radio waves, microwaves, infrared, visible light, ultraviolet, x-rays and gamma rays (listed from longer to shorter wavelengths and lower to higher frequencies) are all part of the electromagnetic spectrum, which differ in wave length and frequency, and that all of them are observed and measured to learn about the cosmos. (See Figure 14.14) The relationship between wavelength and frequency is as follows.

Wavelength = speed of light / frequency .

11. The wavelengths of radiation emitted by bodies are studied by means of devices called “spectroscopes,” which determine the patterns of wavelengths. Such patterns are called “spectra.” There are three broad types of spectra.

> a. Continuous spectra are produced by incandescent solids or gases under high pressure.
>
> b. Emission or bright-line spectra are produced by incandescent gases under low pressure.
>
> c. Absorption or dark line spectra are produced when radiation with a continuous spectrum passes through a cool gas. (Most stars produce absorption spectra because their hot surface emit a continuous spectrum, which then passes through cooler layers in the stars outer layers.)

12. Spectra are extremely useful because they tell us about:

> a. The physical state in the outer part of astronomical bodies.
> b. The temperature of objects.
> c. The composition of objects.
> d. The rotation of objects.
> e. The relative motion of objects with respect to earth.

13. That the Doppler effect can be used to determine whether a distant body is getting closer to earth or moving further away, and how fast it is either approaching or receding. This is the same effect that is used by police to determine the speed of vehicles. If a body is getting closer to the earth, radiation emitted by the body will be shifted toward shorter wavelengths; if it is getting further away, the wavelengths will be shifted toward longer wavelengths.

The Doppler effect can be visualized as follows. Imagine a moving source emitting waves in its direction of travel. The object emits a wave front of light that moves away from the source at the speed of light. Before the next front is emitted, the object moves a certain distance. Thus the next front is closer to the previous one than it would have been if the object had not been moving. And the same is true of each subsequent front. The end result is a series of fronts that are closer together than with a stationary source, and their wave length is shorter, that is, shifted toward the blue end of the visible spectrum. If wave fronts that are moving in the opposite direction as the object are considered, the effect is reversed, that is, the light is red shifted.

14. The intensity of light from astronomical sources decreases proportionally as the square of the distance between source and observer. For example, if the sun were twice as far from Earth as it is, the intensity of sunlight would be only one fourth as great. If the distance to the Sun were half as great, its intensity would be four times as great. This same sort of inverse-square relationship of intensity and distance is true also of gravity

and magnetism.

15. The celestial sphere is an imaginary sphere surrounding Earth on whose surface one can specify the locations of astronomical bodies using a spherical coordinate system. The “zenith” is the point directly overhead of any point on Earth’s surface at any given moment. The “ecliptic” is the apparent path of the Sun across the celestial sphere.

Laboratory

Exercise 18 in Tarbuck, Lutgens, & Pinzke: Patterns in the solar system

WEEK 5

Reading: Tarbuck & Lutgens Chapter 20 & 21

Students should know that:

1. Earth is one of the planets orbiting our Sun. It is very nearly spherical in shape and orbits the Sun in one year. It rotates on its axis in one day. Its diameter is approximately 8,000 miles (6400 km). Its axis of rotation is tilted 23.5 degrees from being perpendicular to the plane of its orbit around the Sun. The northern axis currently points almost exactly to a star called "Polaris" or the "North Star," and it does this year around. There is no equivalent star in the southern hemisphere. The tilt of the axis, along with the revolution around the Sun, is what gives Earth its seasons. Earth's northern hemisphere experiences summer at the same time that the southern hemisphere experiences winter. The Earth revolves around the Sun in a slightly elliptical orbit; it is closest to the Sun in January and furthest in June.

2. Earth's "north pole" is the point on the Earth's surface in the northern hemisphere where the axis of rotation intersects the surface. The "south pole" is the equivalent point in the southern hemisphere. The "horizon" is a circle on the celestial sphere formed by the intersection of a plane tangent to Earth's surface at any given location on the surface. The "equator" is a circle around the Earth midway between the poles. The "tropics" of Cancer and Capricorn are parallels of latitude around the earth at 23.5 degrees north and south of the equator. They mark the limits north and south of which the Sun never reaches an elevation of 90 degrees. The Arctic and Antarctic "circles" are parallels of latitude at 66.5 degrees north and south of the equator. North of the Arctic Circle and south of Antarctic Circle the sun does not rise in the winter or set in the summer.

3. The Moon exhibits "phases." Phases are produced because we mostly see only a portion of the Moon, the half that faces the sun and is illuminated by the Sun at any given moment. The various phases are given names. If we are seeing the entire illuminated face, the phase is called "full." If half of the illuminated face is visible, the phase is called "half." If one quarter of the illuminated face is visible, the phase is "quarter; if three-quarters, the phase is "gibbous"; if less than one-quarter, the phase is "crescent; and if none of the illuminated face is visible because the moon is between the Earth and the sun, it is "new."

4. The "celestial sphere" is a very large imaginary sphere centered on Earth, on which the motions of various astronomical bodies are plotted. Because the Earth rotates toward the east, the celestial sphere appears to rotate toward the west. The planets usually move to the east across the celestial sphere, but periodically this apparent motion is interrupted and the planets move west for a time; this motion is called "retrograde" motion and was one of the classical problems of astronomy that had to be explained by any model of the solar system.

5. The apparent motion of the celestial sphere is dominated by Earth's daily rotation. However, if one were to plot the position of the zenith every night at, say, midnight over the course of a year, it would be seen that the zenith moves systematically westward at a little less than one degree per day through the constellations completely around the celestial sphere in the course of a year. This apparent motion is caused by Earth's revolution around the Sun.

6. The Moon has about one fourth the diameter of the Earth and only a little over one percent of its mass. Its surface gravity is about one sixth that of Earth, which is too low to hold an atmosphere. The Moon is thought to have formed when a Mars-sized body impacted the Earth very early in its history. The impact threw a large amount of material into orbit around the Earth and this material coalesced to form the Moon. Much of the Moon's surface is heavily cratered from meteorite bombardment very early in its history. The extensive flat plains on its surface ("maria") formed when large impact craters were filled with lava after impact.

7. The Sun is a star, that is, a large mass of incandescent gas, mostly hydrogen and helium. The Earth's average distance from the Sun is approximately 150 million kilometers (about 93 million miles). It gets its heat from the fusion of hydrogen nuclei into helium nuclei in its core where temperatures exceed ten million Kelvins (about ten million degrees Celsius). The Sun's "surface" temperature is about 6000 Kelvins. Its diameter is more than a hundred times that of Earth, and its mass is more than 300,000 times that of Earth.

8. Earth gets virtually all of its heat from solar radiation. The intensity of solar radiation is controlled by the surface temperature of the Sun, by its surface area, and by Earth's distance from the Sun. The intensity of solar radiation at Earth's surface is controlled by these factors, by atmospheric characteristics, and by the elevation of the Sun in the sky. In a very general way, solar intensity falls off from the equator toward the poles, but there is a great deal of variation due to the inclination of Earth's axis, Earth's revolution around the Sun, and the weather.

Earth's axis of rotation is tilted 23.5 degrees away from being perpendicular to the plane of the ecliptic. The orientation of the axis changes very slowly and for many hundreds of years it points in nearly the same direction in space (toward Polaris at the moment). As the Earth revolves around the Sun the tilt of the axis results in first the northern hemisphere and then the southern hemisphere being more exposed to the sun. The hemisphere that is more exposed experiences summer, the one that is less exposed, winter. So, when it is summer in North America, South America is having winter, and vice versa.

Because the Earth is illuminated and heated by the Sun, only one side of the Earth is illuminated and heated at any one time; the other side of the Earth is dark at that time. As the Earth rotates, the dark and light zones migrate around the Earth from east to west causing day and night.

Since the sense of Earth's rotation is toward the east, the Sun rises in the east and sets in the west, as does the Moon. The specific direction to the rising and setting Sun and the specific times of sunrise and sunset are controlled by the rotation and by the tilt of Earth's axis to the plane of the ecliptic. For example, in middle northern latitudes the Sun rises earlier and sets later, rises and sets north of due east and west respectively, and rises higher in the sky during the northern hemisphere summer. In the northern hemisphere winter, the sun rises later and sets earlier, rises and sets south of due east and west respectively, and does not rise as high in the sky at noon.

9. The Sun exhibits "differential rotation, thereby demonstrating that it is a fluid. At the equator its rotational period is about 25 days, at the poles about 31 days.

10. The Sun has a distinct layered (or shell) structure. Beginning at the center, the shells are as follows.

Core: (from the center outward to 25% of the radius) Temperature and pressure are greatest here, and it is where the energy-generating fusion takes place, producing x-rays and gamma rays, which carry the energy outward by radiation. Convection does not occur, so the helium created stays in the core. The core's density is about 150 times that of water at Earth's surface.

Radiative zone: (from the core out to 70% of the radius) Fusion does not occur and energy is carried outward by photons (radiation). The radiant energy moves slowly because of numerous internal reflections that occur. Convection does not occur.

Convection zone: (from the radiative zone out to the "surface") Most of the energy from the radiative zone is carried to the surface by convection of hot gas.

Photosphere: The outer several hundred km of the sun, from which most of the energy radiates. The temperature varies from about 6400 K at the surface to about 4200 K. A continuous spectrum is produced. The surface of the photosphere consists of millions of "granulations," which seem to be the tops of small convection cells.

Chromosphere: A zone about 1000 km deep in which the density is very low and the temperature is less than 10,000 K.

Corona: A very deep zone above the chromosphere in which the temperature is on the order of one million K for reasons that are not understood.

Solar flare: A brief, sudden outburst of energy from the Sun's atmosphere.

Solar prominence: A region of cool gas in the Sun's corona.

Coronal mass ejection: (CMEs): A brief but enormous outpouring of material from the Sun's corona into space.

Sun spot: A region of intense magnetic intensity on the Sun's photosphere that is cooler than average and, therefore, appears dark. The Sun goes through an 11-year cycle of sunspot activity.

12. The solar system formed by the gradual coalescence of a huge mass of interstellar gas and dust in the form of a "solar nebula."

13. The solar system consists of the Sun, nine known planets, and a large number of asteroids, comets, and meteors. All of the planets revolve in the same direction around the Sun and all of the orbits are nearly in the same plane, which is very near the plane of the Sun's equator. Thus the solar system is a unified whole.

14. The planets of the solar system consist of two groups with similar characteristics.

The four planets closest to the Sun (Mercury, Venus, Earth, Mars) are called the terrestrial planets because they resemble Earth. They are relatively small compared to the other group; they have relatively high densities; they have few moons, and they have relatively little hydrogen and helium in their atmospheres.

The outer four planets (not counting Pluto) (Jupiter, Saturn, Uranus, and Neptune) are referred to as the Jovian planets. They are relatively large, are very massive, have low densities, have lots of hydrogen and helium in their deep atmospheres, and have many satellites.

Mercury's diameter is only 0.4 times that of Earth. It has no atmosphere and no satellites, its surface is heavily cratered, and it is not tectonically or volcanically active.

Venus is nearly a twin of Earth in size, but it is a little less massive. It has a deep, very dense atmosphere composed mostly of carbon dioxide and almost no water. It's surface is hidden by thick clouds of sulfuric acid. Because of its proximity to the Sun and the greenhouse effect of its atmosphere its surface is extremely hot. It has no satellites, and it shows no current signs of volcanic or tectonic activity.

Earth has a diameter of about 13,000 km and an average density about 5.5 times that of water. It has a relatively shallow, low-density atmosphere composed mostly of nitrogen, oxygen, argon, and trace gases including, importantly, water vapor, and carbon dioxide. It has a substantial amount of water, most of it liquid (in the oceans), some of it solid in glaciers, and some water vapor. It is tectonically and volcanically active and has one relatively large satellite. It is the only planet known to have life.

Mars has a diameter about half that of Earth. It has a low-density atmosphere of carbon dioxide and two very small satellites. It has little water at the surface now, but probably had a substantial amount of surface water in the past. It is not known to be tectonically or volcanically active.

There is a belt of asteroids between the orbits of Mars and Jupiter. The asteroids have diameters ranging from about 900 km down very small chunks of rock.

Jupiter has a diameter that is about 11 times that of Earth. It is composed mostly of hydrogen and helium, has an average density only a little greater than that of water, but it's mass is over 300 times that of Earth. It's rotational period is only about 10 hours, so it has a very noticeable equatorial bulge. Jupiter is mostly liquid. It has an outer shell of liquid hydrogen, an inner shell of liquid metallic hydrogen, and a core of icy rock. It is very hot at the center, but nowhere near hot enough to produce fusion. Jupiter has a ring system and more than 15 satellites.

Saturn is slightly smaller than Earth. It also has a short rotational period, a low density (less than that of water), a spectacular ring system, and many satellites. Its composition and structure are similar to that of Jupiter.

Uranus and Neptune are a little less than half the diameter of Jupiter. They also have low densities, short rotational periods, rings systems, and lots of satellites. Their compositions are similar to that of Jupiter. Uranus is unique in that is axis of rotation is tipped in such a way that it rotates "backward" compared to the other planets.

Pluto's status as a planet is now questionable. It seems to be simply one of many small trans-Neptunian objects slowly orbiting the Sun. Pluto's moon, Charon, is relatively large compared to Pluto and it orbits relatively close to Pluto.

15. Comets, asteroids, and meteors are material that is in a sense "left over" from the formation of the solar system. The material of which they are composed is extremely "primitive," and is of great interest for this reason.

16. Beginning shortly after the end of World War II in 1945, the United States and some other countries (notably the Soviet Union) began exploring the solar system. The program began with the launching of probes to extremely high altitudes with rockets. These early steps were followed by the launch of probes to every planet in the solar system except Pluto. This program continues today.

In 1969 the United States launched the Apollo 11 spacecraft with three astronauts aboard to the moon. Two of the astronauts landed on the surface of the moon, marking the first time that humans reached another body in the solar system. Subsequently, several other ships reached the moon. However, it has now been many years since astronauts have been on the moon.

Currently, the US uses a sort of combined airplane/space ship called the "space shuttle" to launch probes into orbit around Earth, and there is an international "station" occupied by humans orbiting the Earth right now.

Laboratory

Exercise 20 in Tarbuck, Lutgens, & Pinzke: The moon and the sun

WEEK 6

Reading: Tarbuck & Lutgens Chapter 22

Students should know that our Sun is a star, that the stars are other suns, and that:

1. Stars are enormous balls of gas that have formed by the aggregation of interstellar matter. They differ from planets in that they are much more massive. Their great mass means that their gravitational field is very strong, strong enough to produce pressures and temperatures (exceeding ten million Kelvins) in their cores that are high enough to cause nuclear fusion to occur. This nuclear fusion produces enormous quantities of energy that keep the stars hot for millions to billions of years. Because stars are hot enough at their surfaces to radiate visible light, and because they are so large, they radiate enormous quantities of energy. This radiant energy allows them to be seen at great distances.

2. The reason stars are so dim that they can only be seen at night from Earth's surface is that they are so far away. For convenience, the distances to stars are often expressed in "light years." The light year is a unit of distance, the distance light travels in one year, almost six trillion miles (over nine million kilometers). The nearest star, other than the sun, is a star called "Proxima Centauri," which is about 4.3 light years from Earth. The stars range in distance beyond that out to on the order of ten billion light years.

3. Stars have a tremendous range of characteristics. Some are enormously brighter than the Sun; some are much dimmer. Some are much hotter than the sun; others are much cooler. Some are much more massive than the Sun, some much less massive. Some are much bigger; some are smaller than the Earth. The key property of stars is their mass. There is a distinct lower limit to their mass, since they must be massive enough to produce sufficiently high core temperatures to cause nuclear fusion to occur. Below that lower limit, fusion doesn't occur, and the body becomes a body much like Jupiter whose internal temperature is too low for fusion to occur. The lower limit seems to be about 0.08 times the mass of the Sun.

There also seems to be an upper limit to stellar mass of about 20 solar masses. More massive stars probably form, but they are very rare because they do not last long. The reason is that very massive stars have very high core temperatures and they consume their nuclear fuel very rapidly and then explode. For example, a star with a mass 20x that of our Sun would have a luminosity greater than 35,000 times that of the Sun, and a lifetime of only about six million years, a tiny fraction of the Sun's estimated lifetime.

4. One convenient way to categorize stars and to understand their history and evolution is to prepare a graph of stellar surface temperatures vs. stellar luminosities. Such plots are called "Hertsprung-Russell diagrams" (or "H-R diagrams") after their originators. On such diagrams most stars plot on a diagonal zone (called the "main sequence") that crosses the diagram from the upper left (high temperatures and high luminosities) to the lower right (low temperatures and low luminosities). Our Sun plots on the main sequence of such diagrams.

There are at least three other regions that contain significant numbers of stars. First, there is a region below the main sequence of relatively hot but low luminosity stars (white dwarfs), which must be very small stars. Second there is a region above the main sequence of relatively cool, high luminosity stars (the “giant” stars). And third, there is a region of hot, very luminous stars on the upper part of the diagram that includes the so-called “supergiant stars.”

5. It turns out that the H-R diagram is extremely useful in studying the evolution of stars because stars tend to follow fairly regular paths across the H-R diagram as they evolve. When stars first form they typically plot on the right side of the H-R diagram and migrate more or less horizontally across the diagram to the left and enter the main sequence. After spending some time on the main sequence, stars complete hydrogen burning in their cores and leave the main sequence by migrating more or less horizontally across the diagram to the right as their surfaces cool and into the giant region of the diagram. Higher-mass stars do this rapidly; low-mass stars very slowly. It is estimated that the Sun will spend about ten billion years on the main sequence. Stars with 10x the mass of the Sun will spend only about 30 million years on the main sequence. Stars with 1/10 the mass of the Sun will spend about three trillion years on the main sequence.

6. Individual stars are pretty much randomly distributed across the night sky, but ancient peoples attributed great significance to what they perceived to be patterns formed by various groups of stars (called “constellations”) and they gave them names. Almost none of the names bear any obvious relationship to the star patterns to which they are given. For example, the constellation “scorpio” (the scorpion) looks nothing like that animal, “pisces” (the fish) does not look at all like a fish, and “Orion” (the hunter) looks nothing like a hunter. About the only exception to this lack of correspondence is the constellation referred to in the English-speaking world as “the big dipper.” In this case the pattern really is a reasonably good representation of a dipper. Classically, the big dipper is known as “Ursa Major,” the big bear, an animal to which the constellation has no resemblance whatever. Most ancient cultures had their own unique names for the constellations.

Constellation names do, however, provide a convenient way method of referring to specific stars, and contemporary astronomers often refer to objects by their positions within the constellations.

7. Because the stars (other than the Sun) lie at such enormous distances from Earth, their distances were not measured until 1838. The most direct way to determine the distances to stars is to measure what is called their “parallax.” Parallax is the apparent change of position of relatively nearby objects against a background of more distant objects as an observer moves. For example, a simple way to observe parallax is to hold up a single finger at arm’s length and to view it first with one eye covered and then the other. The finger will seem to move back and forth against the background of more distant objects. Measuring stellar parallax involves taking a photograph of a star at a given time and then taking a similar photograph six months later, after the Earth has moved to the other side

of its orbit. The method is useful but works only for stars that are relatively nearby. More distant stars are too far away to use this method. Superimposing the two photographs and knowing the optical characteristics of the telescope then allows astronomers to determine the “angular distance” between the two images, and from this the distance can be calculated.

Because even the closest stars are so far away, their parallax angles are extremely small. Remember that there are 360 degrees in a circle, that there are 60 minutes in a degree, and that there are 60 seconds in a minute. The second of arc is thus extremely small; there are 1,296,000 seconds in a circle. The closest star (Proxima Centauri) has a parallax angle of only 0.76 seconds of arc, an incredibly tiny angle. Calculating the distance from this angle, yields a value of 4.3 light years (more than 25 trillion miles). It would take light, traveling at 186,000 miles per second over four years to reach Earth from Proxima Centauri.

8. We now know enough about the behavior of atoms under extreme conditions of the type found in the interiors of stars to work out the life cycle of stars. The most important single determinant of stellar history is stellar mass. Massive stars have very strong gravitational fields, which leads to very high core temperatures and very high rates of nuclear fusion. This means that massive stars use up their nuclear fuel very rapidly and evolve relatively quickly. Low mass stars have relatively low core temperatures and use up their nuclear fuel relatively slowly, hence they evolve slowly. Stars with masses about that of the Sun fall somewhere between those two extremes. The Sun, for example, is about five billion years old and probably has enough hydrogen it its core so that it will evolve slowly for another five billion years or so. After that the Sun will expand and become a red giant for a time, after which it will probably blow off part of its mass before settling down as a white dwarf, in which condition it will remain for many billions of years before cooling off and becoming a black dwarf.

Depending on just how massive they are, massive stars will reach a stage where they are composed entirely of iron, at which point they will undergo gravitational collapse and then catastrophic explosion as a supernova. Again depending on how massive they are, the remnant after the explosion may be either a very small dense neutron star or even a black hole.

Stars less massive than the Sun consume their nuclear fuel very slowly because of their low core temperatures and remain at about the same luminosity for a very, very long time before they eventually cool off and slowly decrease in luminosity.

9. The various types of stars and their characteristics are as follows.

> Supergiants are large, massive, hot stars with high luminosities. Because they evolve rapidly and explode in gigantic explosions, they are relatively rare.
>
> Red giant stars are large, cool, low-density stars with medium luminosities. They form when main-sequence stars have completed their hydrogen burning phase.

White dwarf stars are small, hot, very high density, low luminosity stars that form when main sequence stars have completed fusing their fuel and collapsed to about the size of the Earth. They can persist in this state for a very long time.

Brown dwarf stars have masses so low that their cores barely reach the temperature necessary for hydrogen fusion. For this reason they have very low luminosities and have only recently been detected.

Neutron stars are the collapsed remnants of supernovae. They have diameters on the order of ten km but masses on the order of that of the sun. Their surfaces are very hot, their luminosities are low, and they are incredibly dense. Pulsars are neutron stars that emit "beams" of radiation at their magnetic poles. If Earth happens to be struck repeatedly by such a beam, the star seems to "pulse." Because neutron stars rotate very rapidly, some pulsars have periods as short as a thousandth of a second and are referred to as "millisecond pulsars."

Variable stars are unstable stars that fluctuate in luminosity, size, and surface temperature. Perhaps the best known are the cepheid variables whose periods of brightness variation range from a few days up to about 30 days and whose luminosity increases with the period. They are extremely useful because their distances can be determined from their apparent brightness and period.

Binary stars are pairs of stars that are so close to each other that they orbit around their common center of mass. This makes it possible to calculate their masses from the period and is the most direct way of determining stellar masses.

Black holes are objects whose surface gravity is so high that no known force can overcome it, and neither matter nor radiation can escape from them.

10. The Milky Way is a spiral galaxy, that is, a giant collection of stars and interstellar matter.

A. The stars rotate around the galaxy's center of mass. Just as in our solar system where the planets most distant from the Sun have long periods of revolution, the further the stars are from the center of the galaxy, the longer their periods are. At the distance our solar system is from the center, objects have periods of about 250 million years.

B. Earth is located approximately 30,000 light years from the center of the galaxy.

C. The galaxy includes approximately 200 billion stars and has a diameter of about 100,000 light years.

D. The center of the galaxy is located in the direction of the constellation Sagittarius. The high speeds with which stars located near the center of the galaxy revolve around the center suggests that there is a very massive body, perhaps a black hole, located at the center of the galaxy.

11. The nature of our galaxy was first worked out in 1918 by Harlow Shapley who used the distribution of globular clusters to determine the size of the galaxy and our position in it. Shapley got the size wrong, but that was later corrected when it was realized that the effect of interstellar dust had caused him to overestimate the size.

12. Up until the early 1920s, the Milky Way galaxy seemed to constitute the entire Universe. One of the central problems of astronomy at that time was the nature of what were then called “spiral nebulae.” They were called “nebulae” because it was thought that they were large clouds of gas and situated within our galaxy. In 1924 Edwin P. Hubble identified Cepheid variable stars in the Andromeda nebula, determined their distance, and found that they were much too far away to be located in our galaxy. His work showed that Andromeda is a galaxy like the Milky Way, located well beyond the confines of the Milky Way. Modern estimates of the distance to Andromeda place it more than two million light years from Earth. This work showed that the Universe is enormously larger than previously thought and that all of the thousands of spiral “nebulae” then known are also galaxies in their own right, many of them located much farther away than Andromeda.

13. Over the next several years, Hubble and others measured the distances to many spiral galaxies and also began to determine from their Doppler shifts that almost all of them are red shifted, that is the distance between them and Earth is increasing. In 1929 Hubble showed that there is a rather simple, direct relationship between the red shifts of such galaxies and their distances: the further a galaxy is from Earth, the faster it is receding. This shows that the Universe is expanding and that at some time in the distant past, the Universe must have been much smaller than it is today, that is must have blown up in a colossal explosion, and that it is still expanding. This picture of the origin of the Universe came to be called “The Big Bang.” In 1964, two American physicists, Penzias and Wilson, detected the radiation left over from the initial big bang, thereby firmly establishing the validity of the theory. This radiation is referred to as “the 3 K background radiation” after the apparent temperature of its source. The best current estimates of the age of the Universe is somewhere in the range of 12 to 15 billion years.

Laboratory

Exercise 1 in Tarbuck, Lutgens, & Pinzke: Introduction to mineral identification

Minerals to be identified

Quartz
Hornblende
Feldspar (1 K-spar & 1 plagioclase)
Olivine
Calcite

- Muscovite
- Biotite
- Galena
- Pyrite
- Hematite
- Halite
- Gypsum
- Magnetite
- Augite

When the students complete their work on mineral and rock identification they should be able to identify the minerals and rocks listed without the aid of any printed material.

WEEK 7

Geology

Reading: Tarbuck & Lutgens Introduction, Chapter 1

Students should know that:

1. The Earth formed at the same time as the rest of the solar system by the aggregation of pieces of gas, dust, rock, and metal, and later by the infall of both large and small fragments of material, including comets and meteorites. At one stage, very early in its history, Earth seems to have been struck by a Mars-sized body, which blasted out a large amount of material that eventually formed the Moon. The heat of impacts and contraction melted the Earth and allowed it to differentiate, with the densest material sinking to form the core and mantle. An intense solar wind from the newly formed Sun swept away Earth's early atmosphere. The present atmosphere and hydrosphere formed mostly by degassing of the solid Earth. When plant life developed, it contributed the oxygen to the atmosphere.

2. Earth has a radius of about 6400 km and a concentric shell-like structure. At the center is a dense core with a diameter of about 3500 km composed mostly of nickel and iron. The inner part of the core is solid; the outer is liquid. The Earth's magnetic field is produced by currents in the liquid outer core. Surrounding the core is a rocky mantle with a thickness of about 2900 km, and above that is a rocky crust that ranges in thickness from about 5 to 100 km. The atmosphere surrounding the solid Earth is about 200 km thick, although it has no distinct outer limit.

3. Unlike any other planet in our solar system, Earth has abundant liquid water on its surface. Gaseous and solid water are also abundant, and the movement of water via wind and by flowing as both a liquid (in streams and ocean currents) and as a solid (in glaciers) plays an important role in Earth's surface environment by the movement of material and energy around on the surface. Earth is both tectonically and volcanically active, and these processes, along with the surficial processes of erosion, transportation, deposition, mean that the surface is constantly changing.

4. Earth has a total surface relief (the difference in elevation between the deepest ocean trench and the highest mountain) of somewhat less than 20 km, a small fraction of the 6400 km radius (Only one part in 320). When considered as a planet, Earth's surface is relatively flat and smooth. When considered on a human scale, the surface is extremely rough. Earth's primary relief features are the continents, which stand well above sea level, and the ocean basins whose floors lie well below sea level.

5. Earth's atmosphere forms a relatively thin layer around the planet. Its primary constituents are nitrogen (78%) and Oxygen (21%), but argon, carbon dioxide and water vapor are also important. On a model Earth with a radius of one meter, the atmosphere would be only about three cm thick or deep. On the same model, Mt. Everest would stand

up less than 2mm above sea level and the deepest oceanic trench would be only about that deep. There is no real “top” to Earth’s atmosphere; it simply keeps getting less and less dense as elevation increases. One half of the mass of the atmosphere lies below an elevation of about 5500 m, and about half of what remains lies below about 11,000 m, etc., etc., etc. Most of what we call “weather” occurs in the lower 10 km of the atmosphere, the part called the “troposphere.” Atmospheric “pressure” is due to the weight of the atmosphere.

6. The energy that drives the circulation of Earth’s atmosphere comes from the Sun, and the phenomenon that produces the circulation is unequal heating by the Sun. Unequal heating produces density and pressure differences that cause the air to move by convection. For example, at the equator air is heated and rises. As it rises it cools and water condenses and falls to the surface as rain. Thus, there is a zone bordering the equator on each side that receives large amounts of precipitation. North and south of this zone, there are two zones where air generally descends and is heated by compression as it does so. In these zones precipitation is sparse, and deserts form. (See Fig. 16.19) These large circulatory cells are called “Hadley Cells. (See Fig. 16.12)

Earth’s rotation plays an important role in controlling the circulation of the atmosphere. The Coriolis effect leads to deflection of surface winds to the right in the northern hemisphere and to the left in the southern hemisphere. (See Fig. 16.12)

As air moves it carries water (in all three forms) and heat with it. Thus water that is evaporated from bodies of water (like the oceans and lakes) is carried over adjacent land areas where it falls as precipitation (either rain or snow) and either infiltrates the soil or runs off in streams or glaciers. Water also evaporates in large quantities from the land surface.

7. The outer part of the solid Earth (the lithosphere, which ranges in thickness from near zero at oceanic ridges to perhaps 100 km at oceanic trenches) consists of a small number of large, thin, rigid plates, which move with respect to each other at velocities that range from near zero up to perhaps 15 cm per year (see Figure 7.9). The sections are called “plates” because their vertical dimensions are small compared to their horizontal dimensions. The boundaries between the plates are places where volcanoes and earthquakes occur, and there are three basic types: divergent boundaries (like the Mid-Atlantic ridge) where two plates move away from each other and new plate is created at the ridges; convergent boundaries (like the Japan Trench), where two plates move toward each other and one may sink beneath the other at an oceanic trench or subduction zone, or a plate with continental crust as its upper part may collide with another plate with continental crust (like the Himalayan Mountains), thereby creating a fold mountain range where the two “collide”; and transform faults where two plates slide past one another and lithosphere is neither created nor destroyed.

8. Most earthquakes occur at plate boundaries and the locations of the earthquakes define the plate boundaries. Volcanoes are another common feature at plate boundaries.

9. Earth has seven major plates: the North American, South American, African, Eurasian, Pacific, Australian-Indian, Pacific, and Antarctic plates. Among the minor plates are the Nazca, Juan de Fuca, Cocos, Caribbean, Philippine, and Scotia plates (see Figure 7.8)

Laboratory

Exercise 1 in Tarbuck, Lutgens, & Pinzke: The study of minerals

WEEK 8

Reading: Tarbuck & Lutgens Chapters 2 & 8

Students should know that:

1. Igneous rocks form by the cooling and solidifying of molten material called magma (when it occurs inside the Earth) or lava (when it flows out on the surface). When magma approaches the surface, the pressure due to the weight of overlying rock is lowered, and volatile materials (that is, materials with lower melting and boiling points) like water, carbon dioxide, sulfur dioxide, and argon emerge from solution in the magma and escape to the atmosphere. The pressure of these materials sometimes produces intense explosions and may throw large quantities of material into the atmosphere.

One of the most important factors that controls the texture (that is, the size and arrangement of grains in the rock) is the rate at which the magma or lava cools. If the magma cools relatively slowly deep underground, large grains have an opportunity to grow and a coarse-grained rock like granite is formed. If the magma either gets near the surface or actually flows out on the surface, the lava cools rapidly and only small grains get a chance to form, thereby producing fine-grained rocks like basalt. In some cases a melt may cool so rapidly that no crystals get a chance to grow and a volcanic glass (like obsidian) is formed.

There are other factors that also help determine the kind of igneous rock that form, for example, the composition of the magma, the amount and type of volatiles (particularly water) present, and the viscosity (or resistance to flow) of the magma.

Granitic-type rocks that are rich in quartz, K-feldspar, and Na-feldspar are characteristic of continental crust, whereas basaltic-type rocks that are rich in Ca-feldspar, pyroxene, and olivine are characteristic of oceanic crust.

2. Igneous rocks are classified on the basis of their texture (chiefly grain size) and their mineralogical composition. (See pp. 38-44, specifically Table 2.1)

- A. Composition
  - i. Felsic, acidic, or granitic rocks
  - ii. Basic, mafic, or basaltic rocks
- B. Texture
  - i. Coarse-grained or phaneritic rocks
  - ii. Fine grained or aphanitic rocks
  - iii. Glassy rocks

Specific rocks: granite, basalt, obsidian, pumice, rhyolite, gabbro, tuff, andesite, diorite.

3. Volcanoes are produced when magma reaches the surface and releases lava, ash, and volatiles. Volcanoes can be fascinatingly beautiful, but they can also be incredibly

dangerous and destructive.

Active volcanoes are those that are currently releasing materials from Earth's interior, particularly lava and ash.

Dormant volcanoes are not currently releasing ash or lava, but may do so at any time.
Extinct volcanoes were active in the distant past and are unlikely to become active again. They show no signs of recent activity.

4. Volcanoes are classified on the basis of the type of eruptions they experience and the type of pile of volcanic materials they construct.

Shield volcanoes are very broad and have relatively gentle slopes, even though they may rise to substantial elevations. They typically erupt basaltic lava at high temperatures. Because the viscosity of the lava is low, it tends to flow freely away from the vents and the lava flows cover large areas and have gentle slopes. The primary eruptive material is lava. Mauna Loa, Mauna Kea and Kilauea are all shield volcanoes. Eruptions of such volcanoes are mostly not dangerous and not explosive because the low viscosity magma can flow freely through the vent tubes.

Composite volcanoes (stratovolcanoes) erupt intermediate to silicic lavas that have high viscosities. Such magma and lava does not flow freely and tends to clog up volcanic vents, leading to explosive eruptions and the production of much ash. The ash and lava tend to accumulate near the vents and build up steeply sloping composite volcanoes that are composed of alternating beds of ash and solidified lava. Most of Earth's well-known, destructive and dangerous volcanoes (for example, Mt. Mayon and Mt. Pinatubo in the Philippines, Mt. Fujiyama in Japan, Mt. Vesuvius and Mt. Etna in Italy, Mt. Rainier, Mt. Shasta, and Mt. St. Helens in the northwestern United States (all Cascade volcanoes), are all composite volcanoes.

Cinder cones are small, volcanoes composed almost entirely of volcanic ash blown out of volcanic vents. They are very steep sided and often occur in groups. They are characteristic of the late phases of a given eruptive series and often occur near larger, composite or shield volcanoes. Paricutin in Mexico, and Sunset Crater and Mt. Capulin in the United States are cinder cones.

Volcanoes form in particular relationship to plate tectonics.

Subduction zone (felsic) volcanoes develop when lithosphere slabs sink into the mantle and lower-melting-point materials are melted and rise to the surface forming chains of explosive volcanoes like the Cascade volcanoes of the northwestern United States.

Spreading center (mafic) volcanoes form when magma is extruded at oceanic ridges, for example in Iceland.

"Hot-spot" volcanoes (like Mauna Loa, and the Yellowstone volcanoes) form when lithosphere moves across plumes of magma that come from deep in the mantle, perhaps as deep as the core-mantle boundary.

5. Some igneous rocks solidify beneath the surface when magma is intruded into existing rocks forming various kinds of bodies(see pp. 232-234).

"Dikes" form when magma is intruded in the form of tabular bodies that cut across existing strata and structures.

"Sills" form when magma is intruded between sedimentary beds.

Volcanic "plugs" form when magma is intruded as vertically oriented, cross-cutting masses.

"Veins" are formed when magma fills small cracks in host rock.

"Batholiths" are formed when very large masses of silicic magma are intruded at depth.

6. Another sign of the presence of very hot rock at depth is the existence of geysers and hot springs. Such phenomena develop when ground water circulating in deep rocks encounters rock heated by magma and then rises to the surface, as, for example, in Yellowstone National Park, in Iceland, and in New Zealand.

Laboratory

Exercise 2 in Tarbuck, Lutgens, & Pinzke: Igneous rock identification

Specific igneous rock types to be identified:

Granite	Gabbro	Rhyolite
Basalt	Tuff	Obsidian
Porphyry (andesite)	Scoria	Pumice
Diorite		

When the students complete their work on rock identification they should be able to identify the rocks listed here without the aid of any printed material.

WEEK 9

Reading: Tarbuck and Lutgens Chapters 3 and 4

Students should know that:

1. Weathering consists of the physical breakdown of rock into smaller pieces and the chemical decomposition of rock into different materials, both sets of processes taking place at or near Earth's surface.

Physical weathering processes (pp. 59-61)

a. Frost wedging - water seeps into cracks in bedrock and its expansion upon freezing breaks rocks into smaller pieces.

b. Unloading - removal of overlying rock by erosion allows near surface slabs to break away from underlying rock.

c. Thermal expansion - daily and seasonal changes in temperature cause surface and near surface rock to alternately expand and contract and sometimes to break away from underlying rock. This is a very slow process.

d. Biological activity - plant roots expand and break rock, and burrowing animals move fresh material to the surface where it is exposed to chemical weathering.

e. Chemical weathering - Mineralogical change breaks rock into smaller pieces.

Chemical weathering processes (pp. 61-63)

a. Exposed rock is dissolved by water and broken down into its constituent ions.

b. Water, carbonic acid, and organic acids react with minerals and chemically change them into different materials. The feldspars, amphiboles and micas in granite, for example, break down into clay minerals, limonite, hematite, and various ions (K+, Mg2+, Na+) and silica, which are carried away in solution.

2. Soil is a material that forms at Earth's surface and consists of weathered bedrock, plant and animal material, air, and water in varying proportions. The importance of soil to human life cannot be exaggerated since the continued existence of the terrestrial biosphere depends almost totally on the soil.

Five principal factors control the formation and continued existence of soil.

A. Parent material - Surface and near surface bedrock and transported sediment are the source of the weathered material in soil. If local weathered bedrock is the source, the soil is referred to as *residual*. If the soil forms on sediment that has been moved from its place of origin, the soil is referred to as *transported*.

B. Climate - temperature and precipitation are the most important factors in soil formation because they control both chemical and physical weathering and exert such a strong influence on organic activity.

C. Organic activity - Plants supply most of the organic material to soil, but burrowing animals and microorganisms play an important role. The end product of organic activity is a material called *humus*.

D. Time - Soil requires time to form and develop, and soil formation, like many geological processes is relatively slow. As a general rule, older soils tend to be thicker and better developed.

E. Slope - The slope of the surface on which soil develops determines moisture content and rate of erosion, both of which are important to soil development. Slope direction also plays an important role in the amount of solar radiation a soil receives. Poleward-facing slopes generally receive less radiation, and tend to be both wetter and colder, both of which are important factors in plant growth.

Among the more important soil types are:

A. Pedalfers - Pedalfers form primarily in forested areas that have substantial amounts of precipitation and lots of organic matter. The abundant organic acids and rainfall result in the carrying away of most soluble material like calcium carbonate and the accumulation of iron oxide and aluminum-rich clays. They are the most common soil in the eastern United States.

B. Pedocals - Pedocals form in drier areas, such as much of the western United States where chemical weathering is less intense and calcium carbonate accumulates in the soil.

C. Laterites - Laterites form in wet tropical areas where chemical weathering is very intense and most carbonate and silica are carried away, leaving a soil that consists mostly of iron and aluminum oxides, giving the soil its characteristic red color.

3. Mass wasting consists of the downslope movement of material directly under the influence of gravity. It is controlled by the degree of slope, the amount and nature of the unconsolidated material at the surface, the occurrence of water, and the amount and kind of vegetation. In many cases, mass wasting constitutes the first step in erosion and transportation in that mass-wasting processes move weathered material downslope and make it accessible to stream and glacial erosion. (See pp. 77-84)

3. Erosion and transportation involve the removal of material from one location, its movement to another area by agents such as wind, running water, and glacial flow, and its deposition in the

new area.

Stream flow is the most important of all agents of erosion and transportation (See chapter 4). Signs of running water can be found almost everywhere on land, even in regions that are extremely dry. Some of Earth's most impressive topographic features, such as the Grand Canyon, were carved by running water, and most of the sediment that reaches the world's oceans is transported by streams. Streams transport material in four ways: 1-by rolling and bouncing coarse material along their bottoms (bed load), 2-by carrying medium-grained material in suspension (suspended load), 3-by floating organic material on the surface (floating load), and 4-by carrying ions in solution (dissolved load).

Winds carry large amounts of material such as fine sand, silt, and dust. Because the volume of moving air is so great, because the velocities are relatively high, and because the wind can move over most topographic features, it can carry large amount of material. For example, dust storms from the Sahara often carry fine material far out into and even across the Atlantic Ocean to North America.

Glaciers are extremely powerful agents of erosion and transportation. They can carry extremely large pieces of rock and large quantities of sediment very long distances, even though they do so very slowly.

3. Sediments form by the decomposition and disintegration of rock when it is exposed to the chemical action of water and the physical wear and tear that occurs at the surface (see pp. 42-46). Sediments consist of three kinds of material: pieces (clasts) of preexisting rocks and minerals, ions in solution, and organic material. Sediments are classified by how they form, their grain size, and their composition. Clasts are classed by their size as gravel, sand, silt, or mud. Some sediments form when elements or compounds in rock are dissolved in water or weak carbonic acid (rainwater) and later precipitate when the water evaporates (for example, salt, gypsum, and borax). Other sediments are formed when skeletons of organisms or the resistant parts of plants accumulate at the surface (for example: peat, lime mud, calcareous ooze, or siliceous ooze). Still others form when minerals are decomposed by the action of carbonic acid into clay.

4. Sedimentary rocks form when sediments are lithified, that is, transformed into rock by compression, dewatering, and cementation. Sedimentary rocks are classified on the basis of their mineralogic composition, their grain size, and their mode of formation (see pp. 42-48).

A. Clastic sedimentary rocks form when particles of preexisting rock are cemented together to form rock; for example, the sediment "gravel" forms conglomerate; sand lithifies into sandstone, and mud becomes shale.

B. Chemical sedimentary rocks form when materials dissolved from preexisting rock are precipitated out due to evaporation of the water in which they are dissolved. Such rocks are called "evaporites." Rock salt, gypsum, and borax form in this way.

C. Biological sedimentary rocks form when parts of plants or animals either form rock directly, as in the case of the limestone in coral reefs, or when accumulations of organic materials are lithified into coal, or lime mud into limestone, as in the case of chalk.

Sediments usually accumulate in distinct environments, each of which has its own characteristics.

> Swamps typically accumulate organic matter because there is insufficient oxygen in the water to oxidize all of the organic matter. This organic matter may then turn into peat, then lignite and then bituminous coal if it is buried sufficiently deeply.
>
> Lakes may accumulate carbonate material and form marl or they may accumulate finely laminated clay. Sand may accumulate on their margins. In arid regions, lakes that evaporate a great deal of water may accumulate evaporite deposits of salt or gypsum.
>
> Flood plains accumulate a variety of sediments, such as channel and point bar sands, flood plain silt, or fine mud mixed with organic matter in back swamps.
>
> Deltas, which form where streams enter standing bodies of water, typically accumulate alternating sands and fine muds mixed with organic matter. The coarseness and pattern of the deposits depends on whether the deltaic environment is dominated by tides, waves, or stream currents.
>
> Continental shelves may accumulate various kinds of sediment, ranging from extensive sheets of sand, or mud. If there is little clastic sediment available, carbonate deposits of various kinds may accumulate.
>
> Abyssal plains typically accumulate either fine red or brown mud or, if there is little clastic sediment brought in, calcareous or siliceous oozes may accumulate.

5, Metamorphic rocks form when preexisting rocks of any kind are changed, (that is "metamorphosed") by the action of high temperatures short of melting, high pressures (particularly high directed pressure), and hot water and other chemically active fluids into new and different rocks (see pp. 49-53). Metamorphic rocks are classified on the basis of their textures and mineralogic compositions. Foliated metamorphic rocks have had their elongate and platy mineral grains oriented to parallel each other by directed pressures produced by tectonic activity. Metamorphic rocks that have not undergone such realignment and consist of more nearly equigranular mineral grains are classed as "unfoliated." Among the foliated rocks are slate, schist, and gneiss. The unfoliated rocks include quartzite, marble, and anthracite coal.

Several different kinds of metamorphism are recognized, including regional metamorphism, contact metamorphism, dynamic metamorphism, and hydrothermal metamorphism. Regional metamorphism is produced by the directed stresses imposed by continental collision and leads to the production of foliated rocks ranging through a sequence that reflects gradually increasing temperatures and pressures. The sequence is slate - schist - gneiss. Contact metamorphism occurs when magma comes into contact with rock, heating it and infusing it with fluids from the melt. Dynamic metamorphism is produced when masses of rock on opposite sides of faults are dragged past one another producing shearing and disintegration. Hydrothermal metamorphism occurs when hot fluids from melts circulate through rock, adding some ions, removing others, and causing new and different minerals to form.

Following are some metamorphic rocks and the preexisting rocks from which they form.

Slate - shale, volcanic tuff
Schist - slate
Gneiss - schist
Marble - limestone
Quartzite - sandstone
Anthracite coal - bituminous coal

Laboratory

Exercise 2 in Tarbuck, Lutgens, & Pinzke: Sedimentary and metamorphic rock identification

Sedimentary rock types to be identified

Clastic rocks: Conglomerate, sandstone, shale
Chemical rocks: Rock salt, gypsum
Biological rocks: Limestone, coal, diatomaceous earth

Metamorphic rock types to be identified

Foliated rocks: slate, schist, gneiss
Non-foliated-rocks: marble, quartzite

When the students complete their work on rock identification they should be able to identify the rocks listed here without the aid of any printed material.

WEEK 10

Reading: Tarbuck & Lutgens Chapters 5 & 6

Students should know that:

1. The range of temperatures found on Earth's surface and the physical properties of water (particularly its wide liquid range) allow water to occur commonly and in abundance in all three phases (forms): solid, liquid, and gas. The occurrence of abundant liquid water is particularly important. These conditions are unusual in the solar system. If Earth's surface were as hot as the surface of Venus, all water would be gaseous; if it were as cold as the surface on Mars, virtually all water would be solid. In neither case would complex and advanced forms of life have developed. The unique physical properties of water play an important role in controlling the conditions on Earth's surface.

2. Because water occurs in all three forms at normal surface temperatures, because there is a substantial atmosphere, and because there is a constant influx of energy from the Sun, Earth experiences what is called a "water" or "hydrologic" cycle (see pp. 90-91).

Physical properties of water

A. Melting point, boiling point and liquid range. Water melts at 0 degrees Celsius (32 degrees Fahrenheit) and boils at 100 degrees Celsius (212 degrees Fahrenheit) (at standard pressure). Both the melting and boiling point are unexpectedly high because of water's dipolar structure, and the liquid range is quite large. This leads to the existence of a very large volume of liquid water on the surface in the form of oceans, lakes, and rivers. There is also a large volume of liquid ground water. In addition to the liquid water, there is a large volume of solid water in the form of glaciers, and there is a much smaller, but crucially important, volume of invisible water vapor in the atmosphere. (See Figure 4.1)

B. Water has the unusual property of expanding substantially (about nine percent) when it freezes. This property has several important consequences. When water freezes in rivers, lakes and oceans, it is less dense than the liquid water, and, therefore, it floats. This means that bodies of water freeze from the top down, and that the ice melts when temperature rises in the summer. If ice were denser than water, it would sink and accumulate on the bottom where it might never melt, and many bodies of water would eventually be completely frozen, thereby killing most of the life in them. The expansion of water on freezing also leads to the important physical process of frost wedging, and it is the reason that freezing of one's toes, fingers, or ears may kill the tissues and lead to their loss.

C. Water has a very high *specific heat*, that is, it takes a lot of heat energy to raise the temperature of water, more energy than is required to raise the temperature of almost any other substance. Conversely, when water cools, it releases a large quantity of heat energy. For this reason, large bodies of surface water (lakes and oceans) act to moderate the temperature extremes of nearby land masses.

D. Water has a very high *latent heat of vaporization*, which means that it requires a great deal of energy to evaporate water. The human body takes advantage of this property to keep from overheating when engaging in physical activity, particularly in hot weather. Like any machine, the human body generates waste heat; the more activity, the more waste heat. This waste heat must be dissipated or else the body temperature will rise to unacceptable levels. In fact, the rise of body temperature by more than four or five degrees can be lethal. We stay cool by secreting water through the skin. This water evaporates and, in the process, absorbs large amounts of energy that would otherwise overheat the body. "Sweating" or "perspiring" is, in fact, an extremely effective way to keep cool, and it allows humans to walk, run, and work even in relatively high temperatures.

The high heat of vaporization of water is crucially important in moderating temperature fluctuations at the surface of the Earth. It is, for example, the reason that the daily fluctuation of temperature is much lower in humid than in desert regions. In humid regions, there is likely to be abundant water on the surface and in the soil, and the evaporation of this water absorbs large amounts of energy that would otherwise go toward heating the atmosphere and soil. Conversely, at night, the drop in temperature is usually less pronounced because of the condensation of dew from the atmosphere, which releases energy and retards cooling. In desert areas, there is often little moisture to condense and the temperature drop is greater.

The presence of liquid water in the soil promotes the growth of plants, and plants subsequently moderate the rise of temperature during the day by *transpiring* water, which acts to keep the atmosphere cool.

E. Water also has a high *latent heat of fusion*, that is, it requires substantial quantities of heat simply to melt ice without raising its temperature, and liquid water surrenders substantial heat when it freezes.

Water also moderates temperature by the fact that clouds (water droplets in the atmosphere) reflect solar radiation and are the most important factor in giving the Earth such a high albedo.

Water vapor also plays a role in Earth's radiation budget by absorbing radiant energy from the surface and thereby warming the atmosphere. Water is, in fact, a very important greenhouse gas in the atmosphere.

In summary, the unique properties and abundance of water on earth substantially moderate temperature fluctuations and make Earth's surface a more suitable place for life.

Earth's water

3. The world's oceans hold an estimated 97% of Earth's water; all other reservoirs hold about

3%. Of that 3%: glaciers hold about 2%, ground water about .6%, freshwater lakes about 0.01%, saline lakes and inland seas about 0.01%, soil about 0.005%, streams about 0.0001%, and the atmosphere only about 0.001%.

Driven by energy supplied by the Sun, water moves among these reservoirs in a complex pattern. It evaporates from the surface of land and bodies of water, is carried about by winds and is dropped in the form of rain, snow, and sleet back onto the surface. Of all the water that falls as precipitation on the land, most (perhaps 60%) evaporates and transpires back into the atmosphere, about 30% runs off in streams, and about 10% infiltrates and becomes groundwater.

4. Human society uses so much fresh water that the supply is becoming scarce, particularly in arid regions. The southwestern US, for example has a severe water-supply problem, and two of the major rivers in the region (the Colorado and the Rio Grande) hardly reach the sea anymore; their water is virtually "used up" for human purposes. Most of the water is used for agriculture and winds up in the atmosphere after being evapotranspired. For this reason, water conservation is becoming increasingly necessary.

Another problem is that the most convenient place for cities to dump their (often poorly treated) sewage is into local rivers, and many rivers have become very badly polluted with residential, industrial and agricultural wastes. In many undeveloped countries, the idea of clean drinking water remains a distant goal. The cost of cleaning up the available water is simply too great and hundreds of people die yearly from wasting disease and toxic substances that contaminate their water supplies.

5. Water can be conserved in a variety of ways:

1. By using toilets that use less water per flush. This is now federally mandated.
2. By reducing the amount of lawn area that must be watered and using native plants that do not require watering.
3. By using drip rather than spray or channel irrigation systems.
4. By more careful monitoring of the amount of water used in irrigation.
5. By promoting infiltration to aquifers and lowering the speed and quantity of runoff.

Streams

6. Stream flow and stream channels are extremely common features of the Earth's surface. Even some of the driest areas in the world, like the desert of Saudi Arabia and the coastal desert of western Peru are cut by stream channels. And even though flow in many channels is intermittent and many years may pass with no flow at all, when there is water in the channels, it erodes and transports large quantities of sediment. Streams can be of any size from the smallest rivulet to the largest river of all, the Amazon. Similarly, stream valleys can also be of any size, from the smallest rill to a mighty canyon like the Grand Canyon of the Colorado River.

Glaciers

7. Glaciers are large masses of ice that form where the accumulation of snow in the winter is

greater than the melting of that snow in the summer. Eventually the weight of the accumulated snow and ice becomes so great that the underlying ice begins to flow slowly, driven by the force of gravity, by either plastic deformation or basal slippage (See pp. 126-128). The two major types of glaciers are continental ice sheets (like those blanketing Antarctica and Greenland) and alpine glaciers that form in high mountainous regions. The Rocky Mountains of the western United States, for example, have many glaciers developed on them.

Glaciers are extremely efficient erosional and transporting agents. They can move sediment of any size, ranging from the finest clay to giant boulders as big a house.

8. In the recent geological past, Earth’s glaciers have been much more extensive, particularly in the northern hemisphere, where they covered large areas of North America, Europe, and Siberia that are now largely free of ice.

Ground Water

9. Approximately ten percent of water that falls as precipitation infiltrates into pores and cracks in solid and bedrock and becomes ground water (see pp. 106-118). Ground water constitutes an extremely valuable and useful resource. It is, for example, a source of drinking water for billions of people, and it can be used without treatment in many cases. It is also extensively used for agriculture. Many people have misconceptions about the nature of ground water; they think it occurs localized in discrete underground streams when, in fact, such streams are relatively rare. Most ground water occurs widely dispersed beneath the surface in the pores of rocks and soil where it moves in response to gravity and pressure gradients created by gravity.

When water infiltrates the soil, some of it moves downward until it reaches a level where the pores are saturated with water. Above that level, at least some pores are filled with air. The surface between the two zones is called the *water table*, and the zone below the water table is called the ground water reservoir. The water in the ground water reservoir flows slowly in response to gravity and pressure and may move long distances underground at very low velocity. If the water table intersects the surface at certain points, water may flow out of bedrock and onto the surface in the form of *springs*. Lakes and streams may either receive groundwater or contribute water to the ground water reservoir.

As water moves through soil and rock, it may have material removed from it or it may pick up and carry away material. For example, as surface water infiltrates most of the particulate matter it may be carrying is removed because the particles are too large to pass through the pores in rock. In this way, ground water is purified by removal of undesirable materials and microorganisms. Ground water sometimes also dissolves soluble material such as calcium carbonate and, in the process, creates extensive systems of caves. In some areas of limestone bedrock, both the surface and the subsurface have been extensively eroded by groundwater, creating a type of topography called *Karst topography* (p. 117). Karst topography is characterized by the occurrence of numerous sinkholes and poorly developed surface drainage.

Earthquakes

10. Earthquakes are not uniformly distributed over the Earth. They tend to be strongly concentrated in narrow, linear belts that encircle the Earth. The reason for this pattern of distribution is that earthquakes occur mostly at the boundaries between the relatively small number of tectonic plates of which the outer part of the Earth consists. These seismically active zones are: 1. The circum-Pacific belt (one part of which is the San Andreas fault), 2. The Alpine/Himalayan belt, 3. And the oceanic-ridge belt. The *focus* of an earthquake is the point within the Earth at which seismic waves originate. The epicenter is the point on the surface immediately above the focus.

There are two general kinds of earthquake or seismic waves: body waves and surface waves. Body waves travel through the interior or body of the earth, and there are two types of body waves: compressional, longitudinal, or “p” waves (actually, sound waves) that travel faster than other kinds of seismic waves and arrive at seismographs first, hence “primary,” and transverse, shear or “s” waves that arrive at seismographs second. Surface waves travel only near the surface of the solid Earth and do not penetrate deep into the interior as body waves do. They also travel more slowly and arrive at seismographs after p and s waves.

The study of seismic waves (seismology) can tell us a great deal about the interior of the Earth (See pp. 174-177). This kind of study demonstrates that the Earth has a layered or shell structure. At the center, Earth has a very dense core, probably composed of nickel and iron. The inner part of the core is solid; the outer part is liquid. Outside the core there is a mantle that is mostly solid except for a thin zone in the upper mantle that is partly (only a few percent) molten. This zone is called the asthenosphere, and it is the zone that flows slowly, carrying the rigid plates of the lithosphere as passengers.

The “size” of an earthquake can be measured in at least two ways.

A. The “intensity” of earthquakes can be determined subjectively by comparing their effects to those specified in a scale called the “Modified Mercalli Intensity Scale” (see Table 6.1). This scale rates earthquakes from I to XII by their effects on humans and human structures. The intensity as specified by this scale drops off with distance from the epicenter, for example, an earthquake that is rated as an “X” in the epicentral region will decrease in intensity to a “V” or lower at some tens of miles from the epicenter.

B. The “magnitude” of earthquakes can be determined by recording the maximum scale reading that an earthquake creates on a seismogram and using that value plus the distance to the epicenter to determine its Richter magnitude. Richter magnitudes range from less than zero to more than 9. The Richter scale is an exponential scale, that is, a magnitude 7 earthquake is much “bigger” than a magnitude 6 quake because it represents a ten times greater seismic wave amplitude and an energy release that is 30 times greater (See pp. 165-167). Richter magnitudes do not vary with distance from the epicenter. Earthquakes with Richter magnitudes greater than 8 are called “great” earthquakes because of their catastrophic effects.

11. Sometimes earthquakes that originate beneath the ocean set off sea waves called *tsunami* that travel great distances at several hundred miles per hour and can cause enormous damage when

they reach shorelines. The height of tsunami is very small in the deep ocean, but as the ocean shallows near shore, the waves slow down but may increase tremendously in height. There is no distinct upper limit to the height of tsunami; most are relatively low, but destructive waves of 10 to 100 feet have occurred many times. In 1960, a tsunami generated by a great earthquake in Chile traveled all the way across the Pacific Ocean and caused a large amount of property damage and many deaths in Japan. Hilo, Hawaii was also damaged by this same tsunami and by many others. Currently, there is a tsunami early warning system that notifies people around the Pacific rim of tsunami danger.

12. Although earthquakes are an inevitable and necessary fact of life on Earth, property damage and loss of life due to earthquakes can be minimized by:

A. Adopting and enforcing strict earthquake building codes in seismically active areas.
B. Adopting and enforcing strict zoning regulations in seismically active areas.
C. Educating the public about what to do before, during, and after earthquakes.
D. Engaging in research on the nature of earthquakes and how the earth and human structures respond to them.
E. Adopting a comprehensive emergency plan for what to do when an earthquake strikes.

Laboratory

Exercise 8 in Tarbuck, Lutgens & Pinzke: Earthquakes and Earth’s interior.

WEEK 11

Reading: Tarbuck & Lutgens Chapters 7 & 10

Students should know that:

1. Mountains are one of Earth's most conspicuous topographic features. There are four kinds of mountains: fold mountains, volcanic mountains, fault block mountains, and upwarped mountains (see pp. 256-266.

> A. Fold mountains are Earth's largest, highest and longest and most structurally complicated mountain ranges. They form when two plates carrying continental crust undergo convergence and the rocks of the crust are subjected to great compressional forces. The Alps, Himalayas, Urals, and Appalachians are all fold mountains. Such mountain ranges have undergone extensive folding, overthrusting, and crustal shortening (see p. 258).
>
> B. Fault block mountains (as typified by the Basin and Range province of the western United States) are formed when large areas of the crust experience tensional forces (see pp. 256-258). Under such forces, extensive systems of normal faults develop and upthrown blocks of the faults rise up substantially with respect to the downdropped blocks. The Grand Teton Mountains of Wyoming are another example of this type of mountain range.
>
> C. Upwarped mountains form when substantial areas of the crust are uplifted and the overlying mantle of sedimentary rocks are removed by erosion, thereby exposing the older metamorphic and igneous rocks of the deeper crust (See p. 258). The Black Hills of South Dakota and the Adirondack Mountains of New York are examples of upwarped mountains.
>
> D. Volcanic mountains are produced when volcanic eruptions continue over a long period of time in the same locality and produce huge piles of volcanic ash and lava, sometimes above subduction zones and sometimes at spreading centers or hot spots. Examples are the Cascade Mountains of the northwestern United States, and the submerged mountains of the oceanic ridge system.

2. The outer part of the Earth (the lithosphere, which ranges in thickness from near zero to about 100 km) consists of a small number of large, thin, rigid plates that move with respect to each other at rates of from near zero to 10 cm per year (See Chapter 7). The plates move on the asthenosphere, which is partly liquid. The major plates are the: North American, South American, Eurasian, African, Indian/Australian, Pacific, and Antarctic (see Fig. 7.8).

The boundaries between the plates are marked by the great global earthquake belts, volcanic activity, and most tectonic activity. The boundaries are classified on the basis of the relative motion of the plates at the boundary, and there are three types: divergent (at oceanic ridges like the Mid-Atlantic Ridge), convergent (at oceanic trenches like the Marianas and Aleutian Trenches, and modern fold-mountain ranges like the Himalayas), and shear (at transform faults like the San Andreas)

3. The evidence for plate tectonics is diverse and extensive.

A. Satellite laser-ranging measurements made over a period of ten years clearly show that the tectonic plates are moving today with precisely the relative motions and rates predicted by plate-tectonic theory, for example, North America and Europe are approaching each other at approximately 1 cm per year.

B. Measurements of magnetic-field intensity made in the world's ocean basins and correlated with the polar-reversal time scale demonstrate clearly that the tectonic plates have been moving with respect to each other for millions of years. These measurements have revealed the precise paths of motion followed by various continental blocks, and the history of those motions confirms in detail the motions discovered by other geological evidence, for example, the northward motion of India for the last 50 million years.

C. Measurement of magnetic inclination of rocks of various ages from various continental blocks confirms the predicted relative motion of those blocks, for example, the movement of Australia with respect to Africa and Antarctica.

D. Deep-sea drilling and study of sediment cores retrieved from the sea floor have revealed that the pattern of sediment thickness and age are precisely those predicted by plate tectonics, for example, both sediment thicknesses and the ages of the oldest sediment found between South America and Africa increase exactly as plate tectonics predicts.

E. The geographic distribution of numerous occurrences of fossil specimens in Africa, India, South America, Australia, and Antarctica strongly support plate tectonics. For example, the occurrence of a medium-size reptile named *Lystrosaurus Murrayi* in southern Africa, India, and Antarctica strongly support the theory, as does the geographic distribution of fossil plants of the *Glossopteris* flora.

F. The geographic distribution of late Paleozoic continental-glacier deposits in southern Africa, South America, India, Australia, and Antarctica, and the absence of such deposits in North America and Eurasia strongly support the idea of continental movement. The direction of ice movement of these glaciers with the continents in their present positions simply does not work. For example, some glacial flow would have to be up and out of oceans and onto continents and some flow would be toward high rather than low latitudes.

G. The jigsaw-puzzle fit of the Atlantic continents strongly supports the idea that those continents were once part of a much larger continental block (Pangaea) that subsequently broke up and whose parts moved away from each other to form the modern continents.

4. Most, but not all, volcanic activity is closely tied to plate tectonics. Some deep-seated volcanic activity occurs within plates. For example, the Hawaiian chain of volcanoes, volcanic islands and submerged volcanic sea mounts clearly marks the passage of the Pacific plate across a deep-seated volcanic source because the lavas in the northwestern part of this chain are much older than those of the southeast to which modern activity is restricted.

However, most volcanic activity is related to plate boundaries.

A. Much volcanic activity occurs at the oceanic ridge spreading centers where the lithosphere is thin and where molten mantle material is close to the surface. As the plates spread, lava is extruded on the sea floor and injected into cracks in the spreading lithosphere. One place where this activity can be seen on the surface is on the volcanic island of Iceland in the north Atlantic. Otherwise, much of the activity takes place beneath thousands of meters of water where it is seldom noticed.

B. A much more conspicuous and dangerous form of volcanic activity takes place at convergent plate boundaries where oceanic crust is sinking into the mantle at what are called "subduction zones." (See Figures 7.9 and 7.13) The volcanism produced at subduction zones is of the explosive type and has produced most of the world's famous (and dangerous) volcanoes, for example, Mt. St. Helens and all of the Cascade volcanoes in the northwestern United States, Mt. Fujiyama in Japan, Mt. Mayon and Mt. Pinatubo in the Philippines, Mt. Etna and Mt. Vesuvius in Italy, and Mt. Tambora, and Krakatoa in Indonesia.

Geologic time

Students should know that:

1. There are two broad methods of determining geological age: relative dating methods and absolute dating methods. Relative dating methods allow one to determine only whether one geological event occurred before or after another. Absolute dating methods allow one to determine how many years ago a given event occurred or how old a mass of rock is in years. The relative dating methods were developed in the late 18th and early 19th century and are still widely used. Absolute dating methods were first developed in the early 20th century and are widely used today. The two kinds of dating compliment one another and can be used as a check on one another.

First type: Relative dating methods (see pp. 274-278)

A. Perhaps the oldest relative dating method involves use of the law of superposition, which says that, "In any sequence of undisturbed sedimentary beds or lava flows or ash falls or flows, the ones on the bottom are the oldest. As can be seen, there are two qualifiers in the rule. The first is the word "undisturbed," which requires that the sedimentary beds not have been overturned by folding or had their positions changed by thrust faulting. The other qualifier limits the kinds of rocks the rule applies to. The rule does not apply to intrusive igneous rocks or to foliated metamorphic rocks that are likely to have been disturbed by recrystallization and/or folding. This rule was and is especially useful in determining the relative ages of fossils.

B. The rule of contact metamorphism says that, if a mass of rock has been metamorphosed at its contact with a mass of igneous rock, the igneous rock is younger.

C. the rule of cross-cutting relationships says that, if a fault (A) or a mass of rock (B) cuts across and truncates another fault (C) or mass of rock (D), then C and/or D is/are older.

D. The rule of inclusions says that, if a mass of rock (A) contains inclusions (pebbles or xenoliths) of rock B, then B is older.

E. The rule of fossil assemblages (or index fossils) says that the ages of sedimentary beds can be determined by the ages of its fossils if the ages of those fossils are known.

One of the interesting and useful features of rocks that can tell us a lot about the history of a given area is what are called unconformities. Unconformities are surfaces that separate rocks of different ages. In some cases the surface represents hundreds of millions or even billions of years of “missing” time. There are three common types of unconformity (See pp. 276-277). In each case the surface of separation marks a time of erosion or non-deposition.

Second type: Absolute dating methods (see pp. 283-288)

One useful method of absolute dating that is useful for fairly recent history is dendrochronology or tree-ring dating. Study of tree rings can tell us a great deal about climate history and individual items (for example, logs used in construction of human habitations) can be dated.

Most absolute dating methods involve the use of radioactive decay. In these methods, the ratio of amount of daughter isotope to the amount of parent isotope is measured in modern rock and this allows us to calculate the age of the rock. Such methods are particularly useful in that they:

a. Allow us to determine how old a rock is in years.
b. Allow us to cross check the ages determined by using different isotope systems.
c. Make use of nuclear processes that are little affected by environmental conditions.
d. Also give us relative ages that we can compare to ages determined by relative-dating methods and puts constraints on relative dates.

The way the decay works is that, over a period of time called the half life, half of the parent decays to daughter isotope, then during the next half life, half of the remaining parent decays.

To understand how radiometric dating works, consider the example of a basaltic magma that is located underground. The magma will have some small amount of potassium-40 in it, and for that reason, it will also have some of the daughter product of K-40, Ar-40 because the K-40 has been decaying ever since it formed in the interior of a massive star (or stars) billions of years ago. Eventually this star blew up in a massive supernova explosion and the K-40 was scattered into the interstellar medium where it eventually became part of the solar nebula and then a part of the Earth. When the magma is extruded onto the surface of the Earth, all of the Ar-40 that is present in the magma escapes into the atmosphere, so the ratio of D/P (that is Ar-40/ K-40) is zero. When the magma has solidified, the Ar can no longer escape if the rock formed is dense and solid. After that, the amount of Ar-40, and the Ar-40 / K-40 ratio, steadily increase as K-40 decays to Ar-40. The ratio reaches one after one half life, three after two half lives, seven after three half lives, and 15 after four half lives. What this means is that, if we can measure the D/P ratio, we can determine how long it has been since the magma was extruded. The key is that some process must take the D/P ratio to zero and that no daughter or parent must escape or be added after that. Crystallization is another process that sometimes meets these conditions.

Among the radioactive isotopes useful for dating are the following:

Parent	Daughter	Half life
U-238	Pb-206	4.5 billion years
U-235	Pb-207	713 million years
Th-232	Pb-208	14.1 billion years
Rb-87	Sr-87	47 billion years
K-40	Ar-40	1.3 billion years
C-14	N-14	5730 years

One of the intrinsic advantages of radiometric dating is that the key process (decay) is a “nuclear” process that occurs deep within atoms and is virtually unaffected by environmental conditions. Thus, the clock just keeps “ticking” at a uniform rate despite changes in temperature, pressure or chemical environment.

The result is that many (but by no means all) rocks and minerals can be “dated,” that is, the number of years since they formed can be determined within the limits of precision of the method, which is usually better than about five percent.

2. Fossils are traces of past life found mostly in sedimentary rocks. These traces are of several types.

A. Original material - Sometimes the original material of organisms is preserved. Hard parts like bone, teeth, shells, and exoskeletons are most often preserved, but soft parts are occasionally preserved in the form of carbon films, or when organisms are frozen or preserved in amber.

B. Sometimes once-living material is replaced by other material, as with silica in the case of petrified wood.

C. Sometimes, when shells are buried, the shell is subsequently dissolved leaving a cavity that has the shape of the original shell. Such fossils are called *molds*. If the mold is later filled with other material, it is called a *cast*.

D. Sometimes traces of organisms are preserved in the form of burrows, footprints, or feeding tracks.

E. In other cases, the organism itself is not preserved, but fossil dung is preserved in the form of *coprolites*, or polished stomach stones are preserved as what are called *gastroliths*.

Fossils are of great interest because they can tell us so much about Earth's history. Among other things, fossils can tells us about:

A. The age of rocks
B. Conditions at the time the fossils lived (paleoecology and paleoclimatology)
C. The history of life, including the origin and evolution of humans
D. Environments of deposition
E. The history of continental arrangements over time

Among other things, fossils tell us that life originated on earth at least 3.5 billion years ago

Geologic time is organized into four major eras

Age of the Earth: 4.6 billion years

Precambrian Era (4.6 to 0.54 billion years ago): earliest forms of life such as bacteria and blue-green algae; later, invertebrates such as jellyfish appeared

Paleozoic Era (540 to 248 million years ago): formation of Pangaea; invertebrate life, such as trilobites, early in this era, followed by amphibians, and the beginnings of reptiles; development of insects, amphibians, and the beginnings of reptiles; development of simple plants, such as mosses and ferns); ended by the greatest mass extinction of all.

Mesozoic Era (248 to 65 million years ago): breakup of Pangaea; "Age of reptiles"; dinosaurs, flowering plants, small mammals and birds; ended by a great mass extinction that killed of the dinosaurs and many other organisms.

Cenozoic Era (65 million years ago to the present): Ice Age; mammoths; gradual development of mammals, birds and other animals recognizable today; humans; flowering plants, forest, grasslands.

Laboratory

Exercise 6 in Tarbuck, Lutgens & Pinzke: Determining geologic ages

WEEK 12

Reading: Tarbuck & Lutgens Chapter 12

Oceanography

Students should know that:

1. Oceans cover about 71% of Earth's surface. The Pacific Ocean is the biggest of the four oceans. The others are the Atlantic, the Indian, and the Arctic oceans.

2. The salt in the oceans originates from materials dissolved from the land and carried to the oceans by streams. The average salinity of the oceans is about 35 parts per thousand, but there is substantial variability in salinity among various parts of the oceans and these variations help produce ocean currents. The variations are caused by evaporation, precipitation, melting of icebergs, and in inflow by rivers. The two most abundant ions in sea water by far are chlorine and sodium. Among the other abundant ions are: sulfate, magnesium, calcium, and potassium.

The elements needed by life (carbon, phosphorus, and iron) occur in relatively low concentrations and limit the amount of living material in the ocean.

3. Temperature and salinity vary with depth in the oceans. There is a surface layer that ranges up to 450 meters thick. Its temperature averages from 21 to 26 degrees C and its salinity tends to be higher than average. Below that there is a transition zone, called the "thermocline" that ranges down to as much as 1500 m deep. Below the thermocline, where most ocean water lies, the temperatures are consistently below about 4 degrees C and there is little variation in salinity.

4. Topographically, the ocean has three major depth zones: a relatively shallow zone near the continents called the continental shelf, which extends from the shoreline out to about 400 m depth; a continental slope that extends down to the deep sea floor, and the abyssal plains which average somewhat less than 6,000 m in depth. There are also long, linear ocean ridges (like the Mid-Atlantic Ridge) that rise perhaps 2,000 m above the abyssal plains in many oceans, and there are long, linear, deep oceanic trenches that reach almost 11,000 m in depth, for example, the Marianas Trench. Many oceans also have volcanic islands that are the exposed tops of volcanoes that project above the sea floor. In some cases these volcanic islands have subsided after initially rising above sea level and coral reefs formed on the volcanic cones and have grown upward as the volcanic peak sank, leaving coral islands and atolls that just barely project above sea level.

5. The edges of the continental shelf are cut in many places by long, deep "submarine canyons" (like the Hudson Canyon off New York City) that were cut by turbidity currents (mixtures of sediment and water) that flow down the canyons because of their high density. At the mouths of these submarine canyons, deep-sea fans of graded sediment have been deposited by the turbidity currents.

6. Wave action on coastlines produces a number of characteristic erosional and depositional

features, including offshore bars (barrier islands), baymouth bars, beaches, arches and stacks, and wave-cut cliffs.

7. Deep-sea sediment accumulates in the deep ocean far from any land. It consists of several predominant types.

A. Terrigenous mud that originates on land and is carried by currents far from shore where it slowly settles to the bottom to accumulate as red or brown clay. Typically it accumulates very slowly, at perhaps a meter per million years.

B. Calcareous ooze consists of a mixture of terrigenous clay and the shells of microorganism that secrete calcareous shells. In tropical areas, where the ocean is not too deep, such material accumulates relatively rapidly at a rate of perhaps 10 m per million years. If the ocean is too deep, and productivity is not too high, the shells dissolve before they reach the bottom.

Deep-sea sediments are relatively thin. The vast majority of deep-sea sediment is less than 500 m thick and large areas of the ocean have only between 100 and 200 m. The reason for this is that the sediment accumulates relatively slowly, and that, because of plate tectonics, the sea floor is relatively young and hasn't had enough time to accumulate large thicknesses of sediment.

Laboratory

Exercise 9 in Tarbuck, Lutgens & Pinzke: Introduction to oceanography

WEEK 13

Reading: Tarbuck & Lutgens Chapter 13

Students should know that:

Waves

1. Most ocean waves are produced by wind. Their height is determined by the velocity of the wind, the length of time the wind has been blowing, and the “fetch” or length of uninterrupted water across which the wind blows. The water across which a wave moves experiences no net displacement but moves in a circular or elliptical pattern, moving with the wave crest as it passes and then moving in the opposite direction as the trough passes. The distance between wave crests is the wavelength; the vertical distance between the wave crest and wave trough is the wave height; and the time between the passage of two wave crests is the period (see fig. 13.12). Near shore the bottom may interfere with the circular motion of water particles and this may cause waves to “break” as they approach the shore (see fig. 13.14).

2. Because most waves approach the shore at some oblique angle, the forward motion of the water in the wave moves along the beach to some degree and this produces a longshore current in the shallow water along the shore and a longshore drift of beach sediment. The net result is that substantial amounts of sediment are transported along the shoreline (see fig. 13.17). Also, as waves approach the shore and begin to be affected by the bottom, they are slowed down. The effect of this is to refract the waves and deflect them toward headlands, which are consequently more strongly attacked by wave erosion, whereas nearby bays experience deposition of material.

3. Erosion, deposition and transport of sediment by waves strongly affects shorelines, tending to erode headlands and fill in bays. The net result is to smooth and straighten the coastline (see fig. 13.23). Wave erosion is very powerful, especially during severe storms, and can often damage or destroy dwellings and shoreline structures such as docks, piers, and lighthouses (see fig. 13.24). During times of rising sea level, as we seem to be experiencing now, shoreline erosion can be particularly damaging and shorelines can move steadily landward.

4. Wave action produces a number of characteristic erosional and depositional shoreline landforms, including wave-cut cliffs, offshore bars, beaches, and spits. (See pp. 346–354)

5. Not all waves are produced by wind. Some waves are produced when earthquakes shake the sea floor, when large submarine or shoreline landslides occur, or when volcanoes erupt in or near the ocean. Such waves are called “tsunami,” and they can be very destructive of human life and property. Tsunami move at very high velocities and can rise to tremendous heights as they approach shore. Most tsunami crests are relatively low, but they can rise to heights of many tens of feet. Because of the bottom configuration of the bay on which it is built and because of its location in the middle of the Pacific ocean, Hilo, Hawaii has frequently experienced damaging tsunami.

Tides

5. Tides are cyclic changes in the height of the ocean surface. They are produced by variations in the gravitational attraction of the sun and moon. Both the sun and the moon produce two tides a day on Earth. Because the moon is so much closer to Earth, it's tides are the greater of the two sets. During times of full and new moon, the two effects reinforce each other and the tides are the highest. The shapes of the continents, and the configuration and sizes of the ocean basins also affect the tides. Tidal currents are produced as the tides rise and fall. Such currents can be very strong if the tides are high and if the configuration of a bay or inlet is favorable. The Bay of Fundy is famous for the height of its tides, and some major rivers experience "tidal bores" or waves as the high tides sweeps up their lower reaches. Tidal currents play a major role in distributing sediment in many shallow bays and gulfs.

Currents:

6. The surface waters of the ocean move slowly but steadily in response mostly to the drag force of atmospheric winds blowing across the water surface. The pattern of these currents is controlled by atmospheric winds, the rotation of the earth, the configuration of the continents, and slightly by differences in salinity and temperature, both of which affect the density of sea water. (See fig. 13.2) Among the important surface currents are the Gulf Stream, the West Wind Drift around Antarctica, the Equatorial current, the Kuroshio current, the California current, and the Labrador current.

7. There are also currents in the deep ocean. These currents are controlled by the surface currents, the configuration of the ocean basins, and the density differences caused by variations in temperature and salinity. Deepwater currents move relatively slowly, for example, it has been estimated that cold, dense water that sinks into the deep ocean will not emerge at the surface again for 500 to 2,000 years. Deepwater currents are important because, among other things, they bring nutrients to the near-surface water where they are used by microorganisms in their growth processes. Such microorganisms constitute the base of the oceanic food chain and are of crucial importance to larger, more complex forms of life.

Laboratory

Exercise 11 in Tarbuck, Lutgens & Pinzke: Waves, current & tides

Mid-term exam (covers chapters 1-6)

1. One of the factors that acts directly to produce Earth's seasons is the tilt of its axis. What is the other?

A. Earth's elliptical orbit
B. Earth's atmosphere
C. Earth's rotation
D. Earth's revolution
E. Earth's varying albedo

2. About what percent of Earth's surface is illuminated by the sun at any one time?

A. 90
B. 75
C. 50
D. 25
E. 10

3. What is the approximate diameter of the Earth in miles?

A. 25,000
B. 15,000
C. 12,500
D. 8,000
E. 4,000

4. Why is the elevation to which airplanes can fly limited?

A. It isn't.
B. Earth's atmosphere ends at 100 miles.
C. The percent of oxygen decreases upward.
D. Atmospheric density decreases upward.
E. Because of the adiabatic lapse rate

5. One of the factors that controls the surface air pressure on Earth is gravity. What is the other?

A. Mass of the atmosphere
B. Air temperature
C. Humidity
D. Ozone content
E. Latitude

6. What are the four shells of the atmosphere called from the surface upward?

A. Mesosphere, troposphere, stratosphere, thermosphere
B. Stratosphere, troposphere, thermosphere, mesosphere
C. Troposphere, stratosphere, thermosphere, mesosphere
D. Troposphere, stratosphere, mesosphere, thermosphere
E. Thermosphere, troposphere, mesosphere, stratosphere

7. Which important atmospheric greenhouse gas is produced by the combustion of fossil fuels?

A. Nitrogen
B. Radon
C. Methane
D. Carbon dioxide
E. Gasoline

8. What name that we use every day is given to the measure of average kinetic energy of the atoms and molecules in a substance?

A. Albedo
B. Humidity
C. Temperature
D. Velocity
E. Lapse rate

9. What do we call masses of tiny droplets of liquid and solid water in the atmosphere?

A. Smoke
B. Clouds
C. Humidity
D. Water vapor
E. Smog

10. What phenomenon produces wind?

A. Albedo
B. Humidity
C. Temperature
D. Differential heating
E. Coriolis effect

11. If a mass of air is heated without gain or loss of water, what happens to the relative humidity?

A. It remains constant
B. It decreases
C. It increases
D. It fluctuates
E. It drops to zero

12. Name one of the three factors that control wind speed and direction?

A. Temperature
B. Elevation change
C. Humidity decrease
D. Pressure difference
E. Oxygen concentration

13. What is the cause of the Coriolis effect?

A. Earth's albedo
B. Solar radiation
C. Earth's rotation
D. Wind
E. Topography

14. When air is compressed with no loss of energy, what happens to its temperature?

A. It increases
B. It remains constant
C. It fluctuates
D. It evaporates
E. It decreases

15. When a mass of dry atmosphere rises, its temperature decreases. What do we call the rate of temperature decrease with altitude?

A. Acceleration
B. Temperature gradient
C. Dry adiabatic lapse rate
D. Adiabatic cooling
E. Greenhouse effect

16. Why does the temperature of a rising air mass decrease?

A. Lapse rate increases
B. Solar energy decreases
C. Water condenses
D. It does work.
E. Its density increases.

17. If the sun were off to your east, in which direction should you look for a rainbow?

A. West
B. North
C. No rainbow could form
D. East
E. South

18. What do we call the average condition of the atmosphere over long periods of time?

A. Weather
B. Temperature
C. Climate
D. Humidity
E. Variable

19. For about how long have instrument-based weather records been kept for most of North America?

A. Since Europeans came to North America
B. Since 1776
C. Since about 1800
D. Since about 1900
E. Since 1950

20. What do meteorologists call a surface that separates masses of air with different characteristics?

A. An isobar
B. An isotherm
C. A front
D. A storm
E. A weather system

21. Earth's axis is not perpendicular to the plane of the ecliptic. How far away from being perpendicular is it tilted?

A. 90 degrees
B. 66.7 degrees
C. 45 degrees
D. 23.5 degrees
E. 10 degrees

22. Where does the peak of the sun's radiation occur in the electromagnetic spectrum?

A. In the microwave region
B. In the infrared region
C. In the ultraviolet region
D. In the radio region
E. In the visible region

23. What is the most abundant gas in Earth's atmosphere?

A. Nitrogen
B. Oxygen
C. Water vapor
D. Carbon dioxide
E. Ozone

24. What is the second most abundant gas in Earth's atmosphere?

A. Nitrogen
B. Oxygen
C. Water vapor
D. Carbon dioxide
E. Ozone

25. What class of air pollutants produces "smog"?

A. Silicate dust
B. Carbon monoxide
C. Smoke particles
D. Carbon dioxide
E. Volatile organics

26. What condition in the core of a hurricane produces a “storm surge”?

A. High wind velocity
B. High air temperature
C. High temperature gradient
D. Low air pressure
E. High air pressure

27. Name a climate “proxy.”

A. Temperature
B. Humidity
C. Thermometer
D. Tree rings
E. Ocean temperature

28. What is the best indicator of climate?

A. Topography
B. Indigenous flora
C. Coriolis effect
D. Bird migration
E. Stream flow

29. What are the two fundamental kinds of optical telescopes?

A. Infrared and ultraviolet
B. Reflecting and refracting
C. Radio and microwave
D. Optical and radio
E. Visible and invisible

30. Name one kind of non-optical telescope.

A. Microwave
B. Surveyors transit
C. Schmidt
D. Mirror
E. Gravimetric

31. Increasing the size of the objective of a telescope improves two aspects of performance. Name one of them.

A. Cost
B. Resolution
C. Focal length
D. Signal/noise ratio
E. Magnification

32. Which was the first human culture to systematically apply rational thought, geometry and mathematics to astronomy?

A. Mesopotamians
B. Chinese
C. Mayans
D. Anasazi
E. Greeks

33. Who developed the “law of gravitation”?

A. Cassini
B. Copernicus
C. Newton
D. Kepler
E. Brahe

34. What European revived the old Greek idea of a heliocentric solar system?

A. Galileo
B. Copernicus
C. Newton
D. Kepler
E. Brahe

35. Who first recognized that planetary orbits are elliptical, not circular?

A. Galileo
B. Copernicus
C. Newton
D. Kepler
E. Brahe

36. Specifically, how does visible light differ from ultraviolet radiation?

A. It is emitted by hot objects.
B. It has longer wavelengths.
C. It has shorter wavelengths.
D. It's amplitude is greater.
E. It is emitted by stars.

37. What instrument is attached to a telescope to determine the composition of stars?

A. A galvanometer
B. An amplifier
C. A Kirchoff lens
D. A spectroscope
E. A pyrheliometer

38. What instrument attached to a telescope is used to determine whether a star (or galaxy) is getting closer to us?

A. A galvanometer
B. An amplifier
C. A Kirchoff lens
D. A spectroscope
E. A pyrheliometer

39. If the distance from the Earth to the Sun doubled, by what factor would the intensity of sunlight diminish at the Earth?

A. 1.414
B. Two
C. Four
D. Eight
E. Twelve

40. What do we call the point on the celestial sphere that is directly overhead at any given moment?

A. Nadir
B. Equator
C. Celestial latitude
D. Peak
E. Zenith

41. What is Earth’s period of revolution?

A. One day
B. One hour
C. One week
D. One month
E. One year

42. What is Earth’s period of rotation?

A. One hour
B. 23.5 hours
C. One day
D. One week
E. One month

43. What percentage of the Moon is illuminated by the sun when the moon is in its “quarter-moon” phase?

A. 10
B. 25
C. 50
D. 75
E. 90

44. If one were to plot the location of the zenith every night at midnight it would be found that the location moves systematically westward. What causes this movement?

A. Earth’s rotation
B. Earth’s revolution
C. Precession
D. Nutation
E. Parallax

45. About how many pounds would a person who weighs 120 pounds on Earth weigh on the surface of the moon?

A. 10
B. 20
C. 60
D. 80
E. 100

46. What is the approximate ratio of the Sun's diameter to Earth's diameter?

A. 1,000
B. 100
C. 10
D. 1
E. 0.01

47. About what percentage of the sun's volume produces energy?

A. 100
B. 75
C. 50
D. 25
E. 5

48. What process is the source of the Sun's energy?

A. Radiation
B. Nuclear fission
C. Nuclear fusion
D. Compression
E. Contraction

49. Which of the following types of bodies are NOT found in our solar system?

A. Pulsars
B. Comets
C. Meteorites
D. Asteroids
E. Satellites

50. Which planet orbits immediately beyond Mars (farther from the sun) in our solar system?

A. Venus
B. Mercury
C. Saturn
D. Sun
E. Jupiter

51. What characteristic of stars determines how long they will last as stars?

A. Density
B. Surface temperature
C. Diameter
D. Mass
E. Distance

52. What are the coordinates of the Hertzsprung-Russell diagram?

A. Density and core temperature
B. Surface temperature and diameter
C. Mass and apparent magnitude
D. Surface temperature and luminosity
E. Luminosity and absolute magnitude

53. Which stars have very low densities, low surface temperatures, and great luminosities?

A. White dwarfs
B. Brown dwarfs
C. Red giants
D. Class O stars
E. Neutron stars

54. White dwarf stars have very high surface temperatures but relatively low luminosities. What other characteristic allows this puzzling combination of characteristics?

A. Small size
B. High apparent magnitudes
C. High absolute magnitudes
D. Great distance
E. High core temperatures

55. What method is used to measure the distances to relatively nearby stars?

A. Red shift
B. Mass/luminosity law
C. Parallax
D. Period/luminosity law
E. Kepler’s law

56. What condition in high-mass stars causes them to have such short lifetimes?

A. Great surface area
B. Low apparent magnitude
C. Great distance
D. High core temperature
E. High velocity

57. What is the fundamental evidence for the expanding Universe?

A. Great size
B. High stellar velocities
C. Newton's third law
D. Red shift of distant galaxies
E. Number of Class II supernovae

Essay questions:

58. Describe the solar system in substantial detail.

59. Explain why massive stars have short lifetimes.

60. Explain why water is so important on Earth.

61. Explain the greenhouse effect.

62. Identify the various factors that control the amount of sunlight that reaches any given location on Earth's surface and explain the effects of each factor.

Final exam (covers chapters 7-13)

1. Which of Earth's "shells" makes up the greatest part of its volume?

A. Core
B. Mantle
C. Crust
E. Asthenosphere
F. Lithosphere

2. Approximately what is Earth's radius in kilometers?

A. 64,700
B. 56,900
C. 26,400
D. 12,800
E. 6,400

3. In which of the atmospheric "spheres" does our weather occur?

A. Troposphere
B. Mesosphere
C. Asthenosphere
D. Stratosphere
E. Thermosphere

4. Most passenger jet planes fly at elevations of around 11,000 m. At that elevation approximately what percent of the mass of the atmosphere is below them?

A. 10
B. 25
C. 50
D. 75
E. 90

5. What single phenomenon best defines the edges of Earth's tectonic plates?

A. Normal faulting
B. Oceanic trenches
C. Continental shelves
D. Earthquakes
E. Continental shoreline

6. How many major tectonic plates does Earth have?

A. Three
B. Seven
C. Twelve
D. Fifteen
E. Nineteen

7. What is the eastern boundary of the North American plate?

A. The Atlantic coastline of North America
B. The edge of the North American continental shelf
C. The bottom of the North American continental slope
D. The Appalachian Mountains
E. The northern Mid-Atlantic ridge

8. Which of the following is the major factor that determines the grain size of igneous rocks.

A. Cooling rate
B. Temperature
C. Melting point
D. Composition
E. Pressure

9. What kind of rock is characteristic of oceanic crust?

A. Granite
B. Sandstone
C. Limestone
D. Basalt
E. Rhyolite

10. What type of volcano are most of Earth's famous and destructive volcanoes?

A. Cinder cones
B. Extinct
C. Lava domes
D. Shield
E. Composite

11. What kind of lava is erupted by shield volcanoes?

A. Rhyolitic
B. Granitic
C. Basaltic
D. Gneissic
E. Intermediate

12. What plate-boundary type are most dangerous volcanoes associated with?

A. Divergent
B. Transform fault
C. Continental collision
D. Spreading center
E. Subduction

13.What are the two major types of weathering?

A. Abrasion and solution
B. Chemical and biochemical
C. Physical and abrasive
D. Physical and chemical
E. Oxidation and solution

14. Four of the factors that control soil development are parent material, climate, organic activity, and slope. What is the fifth?

A. Time
B. Weather
C. Soil type
D. Soil region
E. Porosity

15. What important type of soil forms in tropical areas where intense chemical weathering occurs?

A. Podsol
B. Chernozem
C. Pedalfer
D. Pedocal
E. Laterite

16. Three of the types of stream load are floating, bed, and suspended. What is the fourth?

A. Transported
B. Artificial
C. Dissolved
D. Organic
E. Biochemical

17. Which of the three major classes of sedimentary rock does sandstone belong in?

A. Foliated
B. Chemical
C. Extrusive
D. Biochemical
E. Clastic

18. Two of the agents of metamorphism are high temperature and high pressure. What is the third?

A. Cooling rate
B. Depth
C. Subduction
D. Burial
E. Hot water

19. What sedimentary rock metamorphoses into marble?

A. Basalt
B. Granite
C. Sandstone
D. Limestone
E. Schist

20. Aside from its melting point, what physical property of water plays the decisive role in the occurrence of large quantities of liquid water on Earth's surface?

A. High dielectric constant
B. Specific heat
C. Boiling point
D. Latent heat of fusion
E. Temperature of maximum density

21. What physical property of water causes bodies of water to freeze from the top down?

A. Freezing point
B. Expansion upon freezing
C. High boiling point
D. Specific heat
E. Wind

22. What property of water is used by the human body for cooling?

A. Latent heat of fusion
B. Latent heat of vaporization
C. Boiling point
D. Evaporation
E. Freezing point

23. In what form does most of Earth's fresh water occur?

A. Glacial ice
B. Ground water
C. Sea water
D. Lake water
E. Streams

24. What energy source drives the hydrologic cycle?

A. Wind
B. Geothermal energy
C. Coriolis effect
D. Volcanism
E. Sun

25. What geologic agent produces Karst topography?

A. Volcanism
B. Tectonism
C. Orogeny
D. Groundwater
E. Faulting

26. Two of Earth's three major seismic belts are the Alpine/Himalayan and the Circum-Pacific. What is the other one?

A. The island arc system
B. The Andean-Cordilleran
C. The oceanic ridge system
D. The Uralian system
E. The Appalachian system

27. One of the two kinds of earthquake body waves, that is, waves that travel through the deep interior of the Earth is shear waves. What is the other?

A. Gravity waves
B. Light waves
C. Surface waves
D. Compressional waves
E. Magnetic waves

28. How does the Richter magnitude of an earthquake vary with distance from its epicenter?

A. It falls off as the 4^{th} power of distance.
B. It decreases as the square of distance.
C. It decreases as the square root of distance.
D. It varies as the inverse square of distance.
E. Distance does not affect it.

29. What kind of sea waves sometimes originate with earthquakes and travel at very high velocities across the deep ocean?

A. Tsunami
B. P-waves
C. S-waves
D. Electromagnetic waves
E. Swell

30. What type of mountains are Earth's highest and largest mountain ranges?

A. Fault-block mountains
B. Volcanic mountains
C. Dome mountains
D. Fold mountains
E. Upwarped mountains

31. What plate-tectonic phenomenon leads to the formation of volcanic mountains associated with oceanic trenches?

A. Divergence
B. Continental collision
C. Subduction
D. Faulting
E. Uplift

32. What island in the north Atlantic Ocean straddles the Mid-Atlantic Ridge?

A. Bermuda
B. Greenland
C. Iceland
D. St. Helena
E. Ascenscion

33. What is the most direct evidence for plate tectonics?

A. Fossil occurrences
B. Magnetic anomalies
C. Gravity anomalies
D. Satellite laser ranging data
E. Structural trends

34. What is the boundary of the North American plate in southern California?

A. The Sierra Nevada mountains
B. The Cascade volcanoes
C. The East Pacific Rise
D. The San Andreas fault
E. The Gulf of California

35. Name the two broad kinds of geologic age determination.

A. Absolute and relative
B. Fossils and stratification
C. Radiometric and Seismic
D. Unconformities and stratification
E. Carbon and potassium

36. Name a radioactive parent isotope that is useful for dating geologically old rocks.

A. Calcium-40
B. Thorium-92
C. Uranium-235
D. Carbon-14
E. Lead-207

37. Name a process that can "set a radioactive clock to zero."

A. Stratification
B. Folding
C. Extrusion
D. Burning
E. Erosion

38. Name a principle that is used in relative dating.

A. Folding
B. Superposition
C. Deposition
D. Decay
E. Melting

39. A limestone lies on top of a shale that rests on a basalt flow that rests on a sandstone. The limestone is cut by a fault. There has been no overturning. Which of these is the youngest?

A. Limestone
B. Shale
C. Basalt
D. Sandstone
E. Fault

40. A conglomerate includes pebbles of a granite. The granite has metamorphosed a shale with which it is in contact. The shale rests conformably on top of a sandstone, which lies on top of a limestone. Which of these is oldest?

A. Conglomerate
B. Granite
C. Shale
D. Limestone
E. Sandstone

41. Which of the following organisms is most likely to be fossilized?

A. A jellyfish
B. An oyster
C. An earthworm
D. A dragonfly
E. A termite

42. Fossils are found in two conformable beds of sedimentary rock in a quarry. What rule of relative dating is used to determine their relative age?

A. The law of cross-cutting relationships
B. The rule of inclusions
C. The rule of contact metamorphism
D. The Law of superposition
E. Radiometric dating

43. About how old is the Earth in years?

A. 4,500
B. 45,000
C. 4,500,000
D. 4,500,000,000

44. About how many years ago did life first appear on Earth?

A. 100,000
B. 1,000,000
C. 25,000,000
D. 3,500,000,000
E. 4,500,000,000

45. During which era of geologic time did the dinosaurs live?

A. Cenozoic
B. Mesozoic
C. Paleozoic
D. Tertiary
E. Precambrian

46. Which of the following has the eras of geologic time listed correctly from oldest to youngest?

A. Cenozoic, Mesozoic, Paleozoic, Precambrian
B. Cenozoic, Mesozoic, Precambrian, Paleozoic
C. Precambrian, Paleozoic, Mesozoic, Cenozoic
D. Paleozoic, Cenozoic, Mesozoic, Precambrian
E. Mesozoic, Cenozoic, Paleozoic, Precambrian

47. About what percent of Earth's surface is covered by oceans?

A. 10
B. 25
C. 50
D. 75
E. 90

48. What are the two most abundant ions in sea water?

A. Silicon and oxygen
B. Potassium and silicon
C. Sodium and chloride
D. Carbon and oxygen
E. Silicon and iron

49. What is the approximate temperature in degrees C of deep ocean water?

A. Zero
B. Four
C. Twenty
D. Thirty-two
E. Forty-five

50. Of the oceans major depth zones, which lies adjacent to most continents?

A. Continental slope
B. Continental shelf
C. Continental rise
D. Continental trench
E. Continental shore

51. What are the deepest places in the ocean called?

A. Abyssal plains
B. Oceanic ridges
C. Oceanic trenches
E. Oceanic faults
F. Abyssal slopes

52. Aside from the wind, what is the driving force behind much ocean circulation?

A. Ocean currents
B. Topography
C. Submarine volcanism
D. Density differences
E. Sedimentation

53. What is the average salinity of the oceans in parts per thousand?

A. 2
B. 10
C. 25
D. 35
E. 55

54. Along most coastlines there is a net movement of water parallel to the coast that can transport large quantities of sediment and build spits and bars. What is this water movement called?

A. Contour current
B. Gulf Stream
C. Longshore current
D. Rip tide
E. Tidal current

55. What phenomenon produces these currents?

A. Waves
B. Tides
C. Rivers
D. Tsunami
E. Salinity

56. There is a major ocean current that flows around Antarctica. What is this current called?

A. the Gulf Stream
B. The equatorial counter current
C. The west wind drift
D. The Labrador current
E. The polar current

57. When are oceanic tides the highest?

A. During times of heavy rainfall
B. In the spring
C. During high offshore winds
D. During times of new and full moon
E. During times of strong upwelling

Essay questions:

58. Describe the long-term variation in temperature at your locality. Does the record support the idea of global warming? Explain.

59. Are sandstones good candidates for radiometric dating? Explain.

60. Describe the Earth as a planet. Be specific about its broad characteristics.