Rational Environmentalism

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Chapter 1
Food and Water

FOOD

The most necessary dietary requirement is energy to run our metabolic functions. Energy is measured in kilocalories (1 kcal = 1,000 calories), a chemical unit that books on nutrition refer to as Calories. In this discussion of food we will simply refer to Calories, understanding that they are equal to kilocalories in scientific terms. Most food provides 3–4 Calories per gram, about 100 Calories per ounce.

For most people, the absolute minimum energy intake is in the range of 1,000 to 1,500 Calories per day. People leading active lives, such as athletes, require 4,000 to 5,000 Calories per day, and Americans now consume an average of about 3,500 Calories per day. Women weigh about 10% less than men and consequently require about 10% less food unless they are pregnant or breast-feeding.

Carbohydrates

As the term implies, carbohydrates consist of carbon (C), hydrogen (H), and oxygen (O) although a few compounds with the classification contain small amounts of sulfur (S) and phosphorus (P). The first step in creating carbohydrates is photosynthesis.

The photosynthetic reaction is endothermic, which means that it requires energy. The energy is supplied via chlorophyll (Box 1–1), which gives a green color to leaves and other parts of plants. Chlorophyll absorbs sunlight and releases energy that powers photosynthesis. A simple way to write the photosynthetic reaction is

$$H_2O + CO_2 + \text{solar energy} \rightarrow \text{carbohydrates (plants)} + O_2$$

This simple reaction encompasses three different forms of photosynthesis by different types of plants (Figure 1-1). Most plants are C3 plants, and the first organic molecule is phosphoglycerate (3 carbons). C4 plants have evolved only in the last few million years, and their first organic compound synthesized is oxaloacetic acid

Box 1-1. Antoine Lavoisier

Lavoisier was born in 1743 as the son of a wealthy French nobleman. He became a chemist and is regarded as the "father of modern chemistry." Among his achievements is the law of conservation of mass. Although Lavoisier did not discover chlorophyll, his discovery of oxygen and its effects was very important to the people who did. Lavoisier's careful experiments on oxidation led to the recognition that plants release oxygen.

As a nobleman, Lavoisier also had other duties. Among them was collecting taxes for the king. These duties brought Lavoisier to the attention of the revolutionaries who were establishing a republic. At his trial, Lavoisier claimed to be primarily a scientist. This argument did not sway his judge. When the judge sentenced Lavoisier to death, he said, "The republic has no need for scientists."

(4 carbons). C4 plants include corn (maize) and many plants that flower in the summer. C4 photosynthesis is more efficient than C3, but it requires more energy. CAM plants, such as cacti (Figure 1-2), follow a photosynthetic path similar to C4 plants. CAM is an abbreviation for crassulacean acid metabolism (note that crassulacean refers to a type of plant rather than to a chemical). CAM plants absorb CO_2 at night and store it as organic acids for photosynthesis during the day. This allows them to keep their pores, called stomata, closed during the day in arid environments.

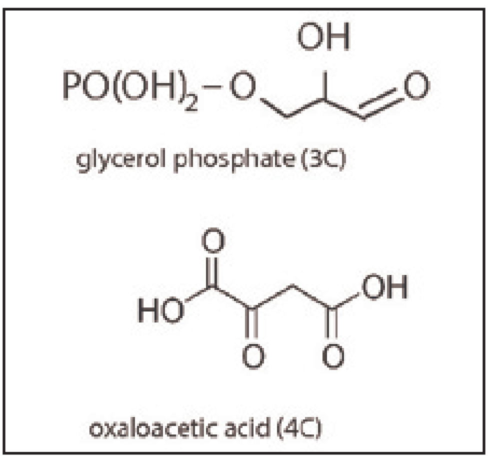


Figure 1-1. Chemical structures of glycerol phosphate and oxaloacetic acid.

Once the initial syntheses have been made, plants proceed to follow the Calvin–Benson–Bassham cycle and synthesize the carbohydrates that constitute plants.

Rice is naturally a C3 plant (Figure 1-3). However, with the help of more than ten million dollars in public and private grants, the International Rice Research Institute (IRRI) is trying find a way to produce rice that is genetically modified to follow a C4 path. This increase in photosynthetic efficiency would greatly increase rice production and help alleviate world hunger.

Figure 1-2 (left). Cholla cactus, a CAM plant.
Figure 1-3 (right). Golden rice compared to white rice in screenhouse of Golden Rice plants. Taken Feb. 15, 2011. Photo by (IRRI).

Significant amounts of carbohydrates do not exist in people, nor other animals. They occur only in plants and are the major part of many plants. The simplest carbohydrate is glucose (Figure 1-4). Glucose contains only one hexagonal ring and is consequently referred to as a monosaccharide. Glucose can be produced from grapes. Fructose is a monosaccharide that is slightly more complicated than glucose. It is particularly abundant in high-fructose corn syrup (Figure 1-5).

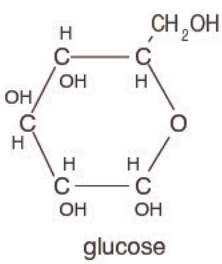


Figure 1-4. Glucose, as do all sugars, is constructed around a very rough hexagon that contains 5 carbon atoms and 1 oxygen. All of the carbons are bonded to 1 hydrogen atom and 1 hydroxyl group, except for the carbon that is bonded to a CH_2OH group. Almost all naturally occurring glucose rotates polarized light to the right (it is "dextrorotary") and it is consequently referred to as dextrose. Bonds between the C atoms and the H and OH are omitted for clarity.

Box 1-2 explores the question of how Americans should use their corn production. Sucrose is a disaccharide consisting of glucose and fructose. It is produced from sugar cane and is the "sugar" that is commonly sold in grocery stores and used as a sweetener in restaurants and industries (Figure 1-6). Almost all naturally occur-

Figure 1-5. Corn fields in Iowa.

Figure 1-6. Sugar cane growing in St. Kitts, an island on the Carribean Sea.

ring carbohydrates occur as long chains of smaller molecules. They form two different varieties (Figure 1-7): starches, which can be digested by people and cellulose, which are indigestible.

Box 1-2. How people use corn

The casual observer of all the corn fields in the Midwest may think that enough corn is produced in the U.S. to feed everyone in the country. However, that observation is wrong. Less than 1% of all that corn is "sweet" or "popping" corn for human consumption. Most of the corn is used for other purposes.

Approximately half of the corn produced is fed to animals, mostly cattle. The steers are brought from grazing pastures to feedlots, where they eat primarily corn. The corn, as a carbohydrate, "marbleizes" the protein in the muscles of the steer. This makes the beef tastier and easier to chew than beef from purely grass-fed cattle. It takes about six pounds of corn to produce one pound of beef.

Some of the corn is also fed to chickens and pig. As discussed later in the book, millions of chickens are slaughtered each year. Some of their "fattening up" results from feeding them corn, although "chicken feed" can consist of almost anything.

A steadily increasing percentage of corn is converted to ethanol as fuel for cars and trucks (Chapter 2). The ethanol substitutes for gasoline and improves burning because the oxygen in the fuel makes the gasoline burn hotter.

About 10% of the corn is used simply to produce high-fructose corn syrup. It is cheaper than sucrose and is used as a sweetener in packaged foods.

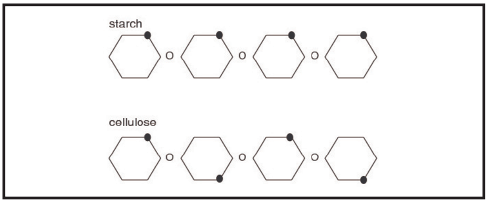


Figure 1-7. Segments of long chains of glucose to show one possible difference between starch (top) and cellulose (bottom). Oxygen atoms in the glucose rings are shown as solid ellipses, and oxygen atoms connecting the glucose rings are shown with the conventional symbol O.

Most plants contain both starches and cellulose. For example, corn (maize) contains starch in the kernels and cellulose in the stalks and the cobs. Trees consist mostly of cellulose (wood), except for those that produce edible fruit. Grasses, including hay, consist entirely of cellulose and consequently provide no nutrition for people.

Many animals can digest cellulose. Termites, for example, eat wood. The largest group of animals is ruminants, including cows, sheep, and goats (Figure 1-8). Some large animals, such as horses and pigs, are not ruminants, but they have enzymes that can digest cellulose in their stomachs. Therefore, in a sense, people use animals to convert cellulose into edible food, which they then eat as meat.

Figure 1-8. Sheep grazing in New Zealand.

Fatty Acids (fats and oils)

Fatty acids occur in both animals and plants. They consist of a COOH group attached to a long chain of carbon-hydrogen groups (Figure 1-9). They are a subtype of a group of chemicals known as lipids, which also include compounds based on glycerol, phospholipid, and fat-soluble vitamins A, D, E, and K. Lipids store energy, help transmit bodily signals, and act as structural components of cell membranes.

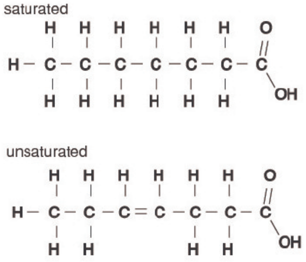


Figure 1-9. Saturated (top) and unsaturated (bottom) fatty acids.

Whether a fatty acid is a fat or an oil depends on the percentage of unsaturated (double) bonds between carbon atoms (Figure 1-9). The “softness” increases from fats, which are completely saturated, to oils, which contain a high percentage of unsaturated bonds. The widely-advertised omega-3 fatty acids are polyunsaturated acids in which the two carbon bonds closest to the CH_3 (omega) end of the acid are saturated and numerous bonds farther away are unsaturated. Omega-3 acids are particularly abundant in fish oil and are one reason that eating fish is considered healthy.

The relatively simple process of partial hydrogenation of unsaturated fatty acids converts oils to “trans-fats.” Prime examples are margarine or other substitutes for butter, which is a fat. Some people show an antipathy toward trans-fats, although there is no real reason to do so.

Most of the fats in the human body are triglycerides (Figure 1-10). These are compounds consisting of glycerol and three fatty acids, which are commonly different from each other. Fats occur in the lower layers of the human skin, where they provide insulation, and as protective layers around vital organs, such as the heart. Fats are also the energy source if food intake is insufficient because people do not store carbohydrates in their bodies.

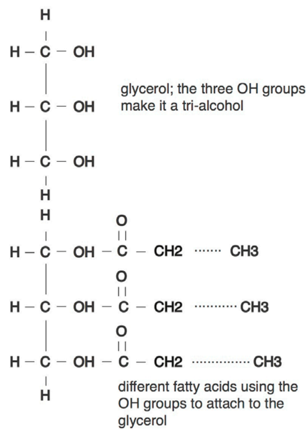


Figure 1-10. Example of a glycerol and triglyceride.

Proteins and Amino Acids

Most of the weight of the human body, discounting bone, is the protein in muscles. Proteins are chains of amino acids that constitute muscles and run most metabolic processes. Examples of these processes include water balancing, nutrient transport, muscle contraction, and formation of enzymes and hormones (Box 1-3).

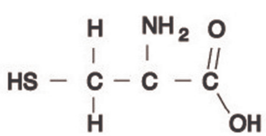


Figure 1-11. Cysteine structure.

Cysteine is an example of a simple amino acid (Figure 1-11). It contains an acid group (COOH) and an amino group

(NH_2). Cysteine also contains sulfur in an SH group. Other amino acids contain long carbon chains and/or benzene rings, and many do not contain sulfur.

Box 1—3. Testosterone

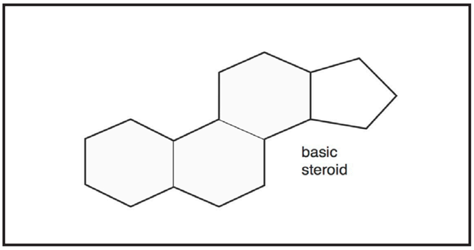
Testosterone, androgen and estrogen are sex hormones and all sex hormones are steroids. Steroids are lipids, like cholesterol, that are built around a 17-carbon structure that consists of three benzene rings and one 5-member ring (Figure 1—12).

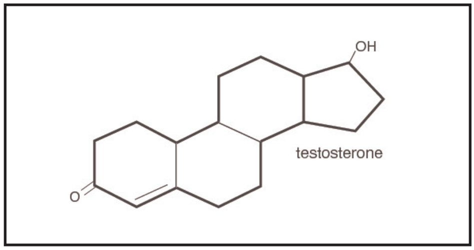
Figure 1-12 also shows the structures of testosterone and estradiol. Estradiol is one of several estrogens that control the physical and emotional features of women. They give women a monthly reproductive cycle, cause the development of breasts, and make women smaller and physically weaker than men. The combination of physical features and the direct influence of estrogens also make women relatively passive and interested primarily in the welfare of their children.

Testosterone is the only significant androgen and it controls the physical and emotional features of men. It makes men large, promotes muscular strength, and makes men aggressive. Men are far less concerned than women in the welfare of their children and far more ready to fight. This "activity" of men compared to the "passivity" of women also shows up in schools. Girls sit through classes and get good grades, whereas boys tend to fidget and get poorer grades.

The willingness of men to use their strength to dominate women, plus the general aggressiveness and restless activity of men and boys, causes furor in the whole world. For this reason, testosterone has been regarded as "the world's most dangerous chemical."

Approximately 500 amino acids are known. Only 20--perhaps slightly more depending on how the count is done--are involved in the formation of proteins. The human body can synthesize all but 10 of these acids, which are regarded as "essential" because they must be consumed by people. These 10 amino acids are leucine, isoleucine, valine, phenylalanine, tryptophan, threonine, methionine, arginine, lysine, and histidine. Each of them is present in meat





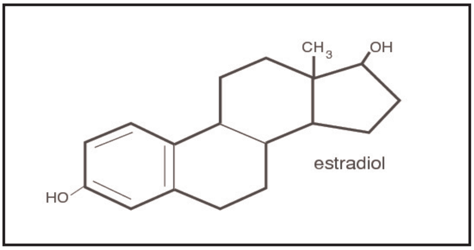


Figure 1-12. Basic steroid structure (top left), estradiol structure (bottom left), and testosterone structure (top right). For clarity, H atoms are not shown. They are distributed around the steroid structures in order to give all C atoms 4 attachments.

and dairy products because all animals except humans can synthesize them. Individual essential acids are also present in vegetables, and the following list shows vegetables that are particularly rich in individual amino acids:

- Leucine: soybeans, peanuts
- Isoleucine: soybeans, seaweed
- Valine: soybeans, seaweed
- Phenylalanine: soybeans, wheat, rye
- Tryptophan: several beans, peanuts, broccoli
- Threonine: several beans, seaweed
- Methionine: cereals
- Arginine: beets, green leafy vegetables
- Lysine: soybeans, peas, broccoli
- Histidine: several beans, peanuts

No single vegetable contains significant amounts of all essential amino acids, but it is not difficult to obtain all of them by combinations of vegetables. These combinations commonly include beans and cereals, such as beans and tacos or beans and rice. Healthy diets should contain about 50 grams of protein for men and 40 grams for women who are not pregnant or breast feeding. Male athletes and men in other strenuous occupations may require 70 grams or more daily protein. Excess protein in a diet requires people to drink a lot of water in order to urinate more to get rid of the nitrogen that is formed by the breakdown of protein and its constituent amino acids.

Vitamins

The term “vitamin” was originally derived from “vital amines.” Some compounds now known as vitamins, however, are not amines. Here is a list of vitamins and their importance:

- **A**: Vitamin A is a set of chemicals, including retinoids obtained from animals, plus carotenes and xanthophylls obtained from vegetables. These chemicals are necessary for healthy eyes.
- **B:** Vitamin B includes at least 8 individual chemicals. All of them are water-soluble amines that are necessary for cell metabolism. They include:
    - B1: thiamine
    - B2: riboflavin
    - B3: niacinamide
    - B5: panthothenic acid
    - B6: pyridoxamine
    - B7: biotin
    - B9: folic acid
    - B12: various cobalamins

Box 1–4. Vegetarians and Vegans

Vegetarians do not eat animals; some avoid meat because they dislike the taste, and some because they are ethically opposed to killing animals.

Many variations occur within these general limitations; for instance, some people eat fish and shellfish because they see nothing wrong with killing fish and other water organisms, such as oysters and shrimp.

Most vegetarians are willing to eat animal products, but not the animals themselves. For example, they drink milk and eat eggs, cheese, and butter, but they will not eat chicken or beef.

Vegans carry vegetarianism to an extreme. They do not eat animals or animal products, including milk and eggs. By careful selection of vegetables, however, vegans can obtain all of the protein and most of the vitamins for a healthy diet. They cannot obtain vitamin B12, however, because it is available only from animal products. This means that vegans must take vitamin B12 in pill or shot form in order to live healthy lives.

- All of the B vitamins are available both in animal products and plants except for B12, which can only be obtained from animal products (Box 1–4).

- **C:** Vitamin C is an L ascorbic acid (the L indicates the molecule rotates polarized light to the left). Ascorbic acid is necessary for the formation of connective tissue; its absence causes scurvy. Vitamin C cannot be synthesized by humans, but it is available in freshly killed animals and all plants (Box 1–5).

Box 1–5. Scurvy

Scurvy used to be the bane of long-distance travellers. It particularly afflicted mariners. It commonly started with lethargy, but it progressed to skin problems, gum disease, loosening of the teeth, jaundice, fever, and death. The cause was a deficiency, or absence, of vitamin C, and the remedy was to provide vitamin C.

The reason for the deficiency in vitamin C is simply that people, and some other primates, are among the few animals that cannot synthesize vitamin C and must obtain it by eating or drinking it. Vitamin C is available in freshly killed animals and in almost all vegetables. It is particularly abundant in citrus fruit.

The English navy began using a remedy for scurvy in the 1800's. The commanders of the ships had a tradition of giving a ration of rum (grog) to every seaman each day. From that tradition, it was simple to proceed to mix lime juice with the rum and stave off scurvy. This tradition led English sailors to be called "limeys."

Mixing prophylactics with liquor was a popular method among English people living on land, as well as those serving on ships. People who wanted to stave off the malaria that was so prevalent in India found a way to make anti-malarial quinine palatable. They mixed it with water, called it "tonic," and drank gin and tonic.

- **D:** Vitamin D is a form of calciferol. Most mammals, including humans, synthesize Vitamin D when they are exposed to sunlight. Inadequate Vitamin D causes low bone density, which can lead to rickes. Most milk is now fortified with Vitamin D.

- **E:** Vitamin E is mostly alpha tocopherol. Vitamin E reduces oxidation of cells; it is an "antioxidant." Vitamin E occurs in most plants.
- **K:** Vitamin K is necessary for blood clotting, and its deficiency leads to bleeding. It occurs in two forms:
    - K1: phylloquinone, available in plants
    - K2: menaquinone, available in animals and produced by bacteria in the human gut.

WATER

Most people need about one half gallon of water per day. This requirement is higher for people who live in deserts and people engaged in strenuous activity, such as outdoor construction workers. The necessary half gallon is generally consumed in a variety of beverages in addition to plain water.

The beverage that most adults consume is coffee. According to the National Coffee Association USA, the percentage of adults that consumed the indicated beverage in 2012 is:

• Coffee	64%
• Soft drinks	50%
• Bottled water	48%
• Tap water	47%
• Tea	46%
• Fruit juice	38%

Slightly more than 10% of adult Americans also drink alcoholic beverages (Figure 1-13). They generally prefer beer (39%) and wine (35%) to hard liquor (22%). Women and men differ markedly in their drinking habits. Women are half as likely as men to drink alcoholic beverages. When they do drink, women prefer wine, whereas men prefer beer. Because ethyl alcohol is a carbohydrate (Figure 1-13), consuming alcohol generates calories. Unreliable data suggest that nearly 5% of the Calories consumed by American adults come from alcohol.

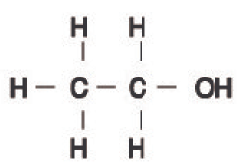


Figure 1-13. Ethyl alcohol (left), also known as ethanol and grain alcohol. Ethyl alcohol is the only alcohol that can be consumed safely. Methyl alcohol (methanol; wood alcohol) causes blindness and death and is used to "denature" ethyl alcohol so that it cannot be consumed. Some operators of illegal stills ("moonshiners") produce methanol along with their ethanol.

PRE-INDUSTRIAL NUTRITION

Hunter-gatherer societies

Before the development of agriculture, people lived by a combination of hunting animals and gathering vegetable products. In most societies, men did the hunting, and women the gathering. The principal animal hunted varied among different parts of the country. In the eastern woodlands, the principal animal was deer, along with some now-extinct woodland buffalo and a few moose. In the Midwestern plains, the principal animal was buffalo (bison), which was hunted nearly to extinction. Fishing, done by men, occurred in fresh water throughout the country and in salt water along the coasts. Clams were also collected from both salt and fresh water. Fish were more important than land animals along much of the Pacific coast.

Gathering was clearly easier in the eastern woodlands than on the prairie. Nuts made an important contribution to diets, along with edible seeds, including wild rice, rye, and sorghum. Sunflower seeds and wild onions were among the plants collected in the prairies. Amaranth was available almost everywhere, and its seeds could be ground into paste to make a poor form of bread.

The combination of meat and vegetable products gave people living in hunter-gatherer societies a very nutritious diet. They had all of the necessary vitamins and amino acids in addition to abundant Calories for a healthy lifestyle. Their problem was that the earth could support only a small number of people living “off the land.” For this reason, it became necessary to develop agricultural societies, which we discuss next.

Start of agriculture in North America

The first agricultural societies developed about 10,000 years ago in the Middle East. Agriculture in North America, however, did not start until about 5,000 years ago. In addition to corn (maize), Native Americans farmed a wide variety of crops. They included numerous types of beans (genus phaseolus), many kinds of berries, squash, pumpkin, and poor-quality tobacco. Some farmers also planted seed crops, such as amaranth and quinoa (commonly pronounced “keenwah”). The amaranth and quinoa seeds could be used to make a poor-quality bread that was inferior to the corn bread made from cornmeal.

Agricultural societies were so productive that not everyone had to be employed in food production. This led to the development of specialists, including men who built houses, made and repaired equipment, and soldiers who defended communities. Some of the people supported by extra food production were rulers and priests, who were commonly the same people. That is, agriculture led to the development of government.

The consequences of the development of agriculture can be shown by extrapolating to the present. In early 21st century America, fewer than 2% of the population is directly engaged in agriculture.

Development of corn (maize)

First, it is necessary to define terms. Outside of America, “corn” refers to all cereals. The London Cornmarket, for example, was the place for marketing such cereals as barley, oats, and rye. In most of the world, people use the term “maize” for the plant that Americans call corn.

Corn/maize is a species of the genus Zea, and the type of maize now raised around the world is the species Zea mays. It is part of a broad group of plants known as “teosintes,” which grow wild in much of Mexico and Central America. Wild teosinte, however, has small ears (cobs) that provide little nutrition.

The development of modern maize from teosinte is controversial. Some kind of mutation clearly occurred, but the cause is unclear. Many investigators now think that teosinte was deliberately crossbred with another plant. This crossbreeding is supported by slight genetic differences between modern maize and wild teosinte.

If investigators are correct about a deliberate crossbreeding, then the maize now raised worldwide is the oldest example of a genetically modified crop. Continued breeding has increased the size of cobs and, thus, increased the number and size of edible kernels on a plant.

Importance of fire

Pre-industrial societies commonly used fire to increase their nutrition. Captain James Cook, following the Australian coast on ships, wrote of seeing “smoke by day and fire by night.” What he saw was an effort by Australian Aborigines to reduce the canopy of the forests that covered Australia. By burning the original forests, the Aborigines allowed light to penetrate to the forest floor and stimulate the growth of plants that the Aborigines gathered for food. This process also left Australian forests dominated by trees that are fire resistant and germinate quickly in burned areas (Figure 1-14).

Figure 1-14. Fire-resistant trees in Australia.

Selective burning was used in many societies that developed pre-industrial agriculture. It was referred to as “slash-and-burn” agriculture, or “swiddening.” The purpose was to burn away the stubble from the pervious crop and prepare to plant the next crop. One problem was the loss of nitrogen from the burned plants, although the ashes would retain the nutrients phosphorus and potassium. The loss of nitrogen could be remedied by planting beans or other legumes, whose roots “fix” atmospheric nitrogen. The burned areas would look like this field in Tanzania, although the fire there was accidental instead of deliberate (Figure 1-15).

Swiddening was never practiced in Europe or colonial America. It was unnecessary where domestic animals could be released into fields that had been harvested. They would eat the stubble and fertilize the field with their droppings. This option was not available to Native Americans, who had no domestic animals (see next section). Partly for this reason, Native Americans burned large areas of their countryside (Box 1-6).

Figure 1-15. Burned area in Tanzania.

Box 1-6. John Lawson

John Lawson was an English explorer. He left Charleston at the end of 1700, made friends with the Native Americans, whom he called 'Indians' and 'savages,' and travelled through the Carolinas until he returned to England. In 1709, he published *A New Voyage to Carolina; Containing the Exact Description and Natural History of That Country: Together with the Present State Thereof And A Journal of a Thousand Miles, Travel'd Thro' Several Nations of Indians, Giving a Particular Account of Their Customs, Manners, &c.*

The book is an effort to draw more settlers to the Carolinas by pointing out how good life could be there. Lawson made reference to the native's use of fire in hunting, including: "Indians firing the Canes Swamps, which drives out the Game, then taking their particular Stands, kill great Quantities of both Bear, Deer, Turkies, and what wild Creatures the Parts afford" and "They go and fire the Woods for many Miles, and drive the Deer and other Game into small Necks of Land and Isthmus's, where they kill and destroy what they please".

Lawson returned to the Carolinas after publishing his book. He found new tribes of natives had arrived and they were hostile to Europeans because of their behavior. Consequently, he was captured and gruesomely killed in 1711.

The quotes from Lawaon's book are from the scanned document at docsouth.unc.edu.

Biotic interchange between the Old and New Worlds

The arrival of European settlers in North America started an amazing interchange of animal and plant foods. The only animal that Europeans took away from the Americas was the turkey, but the list of plant foods distributed to the rest of the world is impressive. Here is a list of the major products taken from the Americas:

- **All varieties of Phaseolus beans**: The genus Phaseolus includes most of the beans that we use today, including lima, green (string), pinto, navy, and kidney. The different varieties evolved in different parts of the Americas, and the type mostly

used by Native Americans along the eastern seaboard was the lima bean. It joined with corn and squash as their primary source of plant food, and fortunately all three of them could be grown together. There are three main genera of beans, but only phaseolus is native to the Americas.
• **Vegetables**: maize (corn), squash, zucchini, tomatoes
• **Potatoes**: They are natives of South America, were taken to Europe, and then brought back to North America.
• **Chocolate and avocados** from Central America
• **Peanuts** (ground nuts) were taken from South America to Africa and then returned to North America by slaves

Europeans also brought animals and plants to the Americas:

• **Beans and other legumes**: European beans are part of a vast family of plants known as legumes, which means that the root system is capable of taking nitrogen from the atmosphere and "fixing" it into ammonia and nitrate that can be used as plant nutrients. The imports included broad beans (genus Vicia) plus such related varieties as chick peas (garbanzos), and green peas. Because the broad beans are not as tasty as native American varieties, they have never been as extensively cultivated, but peas have become a staple of American diets. The third of the major bean genera is Glycine (soybean), which was imported from its home in East Asia and has now become the major bean produced in North America.
• **Domestic animals**: horses, cows, sheep, goats, and pigs. The horses that Native Americans rode were bred from horses that were either stolen or escaped from European settlers.
• **Fruit**: apples, pears, peaches and several varieties of melons arrived with European settlers, although not all before the Revolution. Oranges, lemons, and other citrus fruit developed in India and Southeast Asia and were not brought to the Americas until growers began extensive cultivation of groves in Florida in the 1800's.
• **Wheat**: they arrived with the Europeans, but by circuitous routes. Wheat originally brought by colonists included varieties that matured during the summer and were harvested in the fall. They are relatively low in protein and best used for bread. Later, people brought "hard" varieties (durum wheat) that mature over

the winter and are harvested in the spring. They are richer in protein and best used for making pasta. The final wheat to arrive was a hard Ukrainian strain known as Turkey Red, which arrived with Russian Mennonites in 1873 and has proved so reliable that it now accounts for almost all American wheat.

- **Rice**: the rice that was such an essential crop for colonists in the coastal plain of the Carolinas before the Revolution arrived in the Americas by accident. Originally from India, it was taken to Madagascar by Arab traders and cultivated there. Then, in the early 1600's, as rice was being shipped around the world, a vessel carrying it was wrecked on the coast of South Carolina. After the crew was rescued by local people, the captain gave them two bags of rice that proved to be the seed material for the development of much of the rice industry in the Americas.

INDUSTRIAL AGRICULTURE

Modern industrial agriculture depends on fertilizer, mechanical sowing and harvesting, raising single crops over large areas, and raising animals separately from crops. It no longer uses fire, plants legumes to add nitrogen to soil, and releases animals into harvested fields to eat the stubble and fertilize the field with their droppings. Fertilizers now supply all of the nitrogen, phosphorus, and potassium that plants need. Furthermore, animals receive extra feed in addition to the grass that grows naturally in their pens.

Some of the equipment used is very sophisticated. For example, corn harvesters strip kernels away from cobs and throw cobs and their surrounding husks back into the harvested field. The cobs and husks serve as mulch for the next crop.

Productivity

The most recent year for which there are adequate data for all agricultural products is 2010. Consequently, we report production data for crops in 2010 from Table 858 of the U.S. Census Bureau 2012 Statistical Abstract of the United States. We report statistics on 2010 meat production from the United States Meat Industry (AMI.com).

We should note that the animals slaughtered are almost exclusively male. In addition to having offspring, females are important for other reasons: female cows produce milk (and people make butter and cheese from it) and female chickens produce eggs.

Product	Value in billions of dollars
• Corn	67
• Soybeans	39
• Wheat	13
• Hay	14
• Potatoes	4
	Value in billions of pounds
• Chicken	37
• Beef	26
• Pork	23
• Turkey	6

In order to produce this meat, the industry slaughtered 8.6 billion chickens, 34.3 million cattle, 110.4 million hogs, and 242 million turkeys.

Environmental consequences

The high productivity of industrial agriculture commonly brings serious environmental consequences. Perhaps the most insidious is drainage of nitrogen in fertilizer from agricultural land. The nitrogen is in very soluble forms (nitrate and ammonia). This solubility causes the nitrogen to be widely distributed and to contribute to so much growth of unwanted organisms, such as algae, that so much oxygen is removed from the system that good organisms cannot live; the process is called “eutrophication.” A serious example is the formation of “red tides” in estuaries, where excessive growth of plankton causes fish to die out.

Another consequence is easier to see. Planting row crops like corn and wheat without intervening legumes leaves much of the soil barren and subject to erosion. Long-term erosion simply denudes the soil, but the process can be dramatic. For example, rapid erosion of soil from areas planted in row crops has been regarded as the principal cause of the Dust Bowl in western Texas to western Kansas in the 1930’s. Cutting down forests and planting coffee (a row crop) led to the erosion in Costa Rica (Figure 1-16).

Figure 1-16. Soil erosion in overused area in Costa Rica.

Modern agriculture also commonly requires more water than is available from rainfall and snowmelt. These circular sprinklers in West Texas (Figure 1-17) are spreading water from an underground reservoir. Because they are shooting water into the air, much of it is lost by evaporation.

Some of modern agriculture depends on importing animals and plants to new areas, where they generally do not have predators. Some of these imports break loose and cause massive destruction, as with the imported rabbits in Australia (Figure 1-18).

Figure 1-17 (left). Circular sprinklers wasting water in West Texas.
Figure 1-18 (right). Erosion caused by rabbits imported to Australia.

SUGGESTIONS FOR FURTHER READING

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TOPICS FOR DISCUSSION

- Should we feed corn to cattle?
- Should we make ethanol from cellulose instead of edible plants?
- Should we look for ways to reduce the effect of testosterone?
- Should people eat genetically modified crops?
- Should people eat transfat?
- Should we use irrigation in areas with inadequate rainfall?
- Should we slaughter so many male chickens and cattle?
- Should we plant so many row crops?
- Should we use so much fertilizer?.
- Should we eat so much sugar?

CHAPTER 2
ENERGY

The earth provides an abundance of energy for people to use to run civilization. Some of this energy is stored as fossil fuel, and some is continually supplied as "renewable energy." Our task is not to find energy, but to determine which source is cheapest and how we can use it best. We discuss that problem in this chapter, starting with identification of the units used for energy and power.

Energy and Power Units

Different units are used for a variety of purposes, some of them very specialized. We start with the calorie, which seems to be the simplest. Calories, however, are part of the cgs (centimeter-gram-second) units, which have largely been replaced by the SI (International Standard) units. For example, the calorie has been replaced by the joule, which is an SI-derived unit. Here is a list of various units for energy:

- **1 calorie** (cal) is the amount of energy used to raise the temperature of 1 gram of water by 1 °C. We ignore the very slight variation in the amount of energy needed at different temperatures and pressures. As discussed in Chapter 1, a food Calorie is 1000 calories (1 kilocalorie).
- **1 joule** (J) is the amount of energy generated by a force of 1 newton through a distance of 1 meter. 1 Joule is also the amount of energy needed to move an electric charge of 1 coulomb through an electric potential difference of 1 volt (electron volt, eV), and it is the energy needed to produce 1 watt of power for 1 second.
    - 4.18 J = 1 cal
- **1 British thermal unit** (btu) is the amount of energy needed to raise the temperature of 1 pound of water by 1 °F. Natural gas is mostly sold in terms of btu (1 btu = 1055 J) generated by the amount of gas sold, and both coal and oil are commonly evaluated in terms of btu that they can generate. 1 quadrillion btu (1 quad = 10^{15} btu) is a useful unit for measuring the amount of energy consumed by countries and by the world as a whole.

Power is energy used per unit of time. Various units are used for this purpose:

- **1 horsepower** (hp) was originally defined as the power generated by a British draft horse. Because that power is so variable, hp is now defined in different ways for different purposes. For instance, 1 hp = 746 watts for mechanical use. For convenience, automobile and other engines that do mechanical work are commonly rated in terms of hp instead of watts. Boilers that produce electricity are rated 1 hp = 9810 watts.
- **1 watt** (W) = 1 joule per second (J/sec). Watts are commonly expressed as kilowatts (kW). Electricity-generating plants commonly report their energy generation in terms of kilowatt-hours (kW-hr).

Importance of Rotation

Rotation has been recognized as a necessity since antiquity. Perhaps the first use was in grinding grain. Before the development of such mechanical devices as waterwheels, rotation was supplied by animals or people. Mules or oxen were hitched to wheels and driven around in circles. Prisoners taken in war or other slaves were also forced into this type of labor.

As society gradually became more accustomed to the use of mechanical instruments, human and animal power was replaced by waterwheels and similar devices. At this time, many mills were built along streams, and small dams were constructed to provide a steady flow of water (Figure 2-1). The power generated by water wheels can be measured only by using them to produce electricity. Small wheels in ordinary streams can generate a few tens of watts.

Figure 2-1. Water wheel at Hagley, Delaware. Formerly used by Du Pont, but now a museum. Photo by Ad Meskens.

Most water wheels are vertical, and mechanisms had to be designed to rotate other wheels horizontally. These horizontal wheels were used to grind grain and, as the industrial revolution developed (Box 2-1), to make the myriad of products required by society.

Box 2–1. Industrial Revolution

In the late 1700's, the use of coal and further development OF water wheels started what is known as the "Industrial Revolution." It was a time when people moved out of rural areas and concentrated in cities near factories. Goods, Such as articles of clothing, that used to be made individually by hand were now made in bulk by workers using machines. This industrialization began earlier in England than in other countries because English coal is closer to the surface and more accessible.

The results of industrialization were generally positive. Manufactured goods were cheaper than those made by hand and more plentiful. This made them more available to ordinary people, not just the rich.

There were, however, some drawbacks. Factory workers became bored with repetitive jobs. People's health declined because they no longer did healthful labor outside, but were now stuck inside at mostly sedentary jobs.

The environment also suffered from the burning of coal. London was particularly affected. White buildings were turned gray by coal ash and tars in smoke. Many buildings were not cleaned until the 20th century. Smoke was probably responsible for much of the fog.

Prevailing west–to–east winds even carried pollution as far as Norway. The effect is shown by this observation: "Britain's coal smoke, foul and black, sinking o'er the land is seen. Cloaks and smirches in its track every freshening shoot of green." The quotation is from *Brand, a Dramatic Poem* by Henrik Ibsen, translated by F. E. Garrett.

Rotation became even more important when people began using electricity. As we discuss later in this chapter, all electricity is produced by rotating turbines.

Direct Combustion

Fossil fuels and biomass are produced by photosynthesis (see Chapter 1). Animals, including people, that eat the plants or eat animals that ate plants carry solar energy with them and ultimately use it to run their metabolism. People can also burn fossil fuels and biomass (including wood) to obtain energy. The process is an exothermic reaction that is the reverse of photosynthesis (see Chapter 1) and can be written

$$\text{Carbohydrates} + O_2 \longrightarrow \text{energy} + H_2O + CO_2$$

Respiration and burning put carbon dioxide and water in the atmosphere. Respired water has always been insignificant compared to other atmospheric sources, but before we began burning fossil fuel, most of the carbon dioxide in the atmosphere came from animal respiration.

Coal

Figure 2-2. Okefenoke Swamp where coal might accumulate, Georgia.

Coal is produced from plants that decay mostly under water (Figure 2-2). The water prevents oxygen from reaching the dead plant material and, in effect, from "burning" it up before it can accumulate. Plant remains that initially accumulate this way are referred to as "peat" and create no more energy than fresh plants (Figure 2-3). Burning peat creates a lot of smoke and is done only by people who cannot obtain a better source of heat.

Figure 2-3. Peat on Skye, Hebrides Islands, Scotland.

Increasing temperatures and pressures convert peat into coal. This "metamorphism" drives out water and generally reduces contaminants such as sulfur. The process makes coal more useful as temperatures and pressures increase.

The lowest grade coal is a brown coal that is referred to as "lignite." It has been metamorphosed sufficiently that individual plant remains cannot be recognized, but it retains a high water and sulfur content. It has a carbon content of about 50% and produces less than 10,000 btu/lb. Burning lignite creates a lot of smoke and places a lot of sulfur and other contaminants in the atmosphere.

"Bituminous" coal is most of the coal that we mine (Figure 2-4). It has been metamorphosed to temperatures less than about 200°C and subjected to burial pressures of a few hundred meters of overlying rock. Bituminous coal ranges from "sub-bituminous," which is black but only contains about 55-60% carbon, to coals that are almost anthracite. Typical bituminous coal yields up to 15,000 btu/lb when it is burned. Bituminous coal fueled the Industrial Revolution of the late 1700's (Box 2–1).

Figure 2-4. Area that has been surface mimed for coal, West Virginia.

"Anthracite" is the highest grade of coal. It is shiny black, contains 90% or more carbon, and yields more than 15,000 btu/lb. It produces very little smoke and pollution when it is burned. Metamorphic temperatures higher than 250°C are generally necessary for formation of anthracite.

Anthracite is comparatively rare, and most of the anthracite has been mined out of the Pennsylvania Appalachians, which was the primary source in the U.S. The principal exporting countries are now Russia and China.

Statistics about coal reserves, production, use, and trade are almost entirely about bituminous coal. The World Coal Association compiled information from a variety of sources to produce the following summary of five countries with the largest proven coal reserves, in metric tons (1,000 kg) of oil:

- USA 122,000
- Russia 68,700
- China 58,900
- India 55,600
- Australia 41,500

In terms of metric tons of coal, worldwide reserves are estimated to be nearly 1,000 billion tons, equal to approximately 100 years production at slightly more than 6,000 tons annually.

Coal is used primarily to generate electricity. The U.S. generates about 45% of its electricity from coal. Some countries generate more than half of their electricity from coal. They include China, Australia, India, Israel, and Greece. Thirteen percent of coal production is used in steel production (see Chapter 4).

In 2011, the major coal exporting and importing countries were, in metric tons:

Exporters:

• Indonesia	309
• Australia	284
• Russia	124
• USA	97
• Colombia	75
• South Africa	72
• Kazakhstan	34

Importers:

• China	190
• Japan	175
• South Korea	12
• Germany	41
• Britain	33

Oil and Gas

The organic remains that develop into oil and gas usually initially accumulate in marine environments. The rate of accumulation of organic remains must exceed the rate at which oxygen destroys the remains.

This accumulation forms a “source rock.” Conventional drilling requires the oil and gas to “migrate” to a reservoir. Reservoirs are made by various geologic processes (Figure 2-5), but they all share two features: they have caps that keep the oil and gas in the reservoir because the caps are impermeable and they almost all have floors of water, with the oil floating on the water.

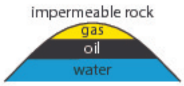


Figure 2-5. Basic features of oil reservoirs.

By the time oil and gases reach a reservoir they have “matured” because of the high temperatures encountered as they are buried deeper in the sedimentary basin that they are found in. Temperatures of about 60 °C are necessary for the formation of oil and higher temperatures promote formation of more natural gases, which consist of methane and ethane.

Crude oil consists of a variety of compounds. About a third is “paraffins,” which are aliphatic chains of a range of lengths. Roughly half of crude oil consists of “naphthenes,” which are cyclic aliphatic hydrocarbons with the general formula C_nH_{2n}. A small proportion of crude oil is aromatics, based on benzene. Light crude oil, as the name implies, consists of molecules with relatively few carbon atoms. It has a low viscosity and flows easily. Sweet crude oil is low in sulfur, and sour crude oil is high. Obviously “light sweet crude” is best and brings the highest price.

Crude oil is taken to refineries for processing into different products. This process generally involves cracking to form light molecules from heavy ones. Molecules with 5 to 7 carbons are easily vaporized, clear liquids. They are used as solvents, including paint solvents and dry cleaning fluids.

Molecules with 7 to 11 carbons are used for gasoline, and those with 12 to 15 carbons form kerosene. Molecules with 16 to 19 carbons form, at increasing heaviness, diesel fuel, fuel oil (including heating oil for houses), lubricating oil, and semi-solid grease. Molecules with more than 20 carbons are mostly solid, forming tar and, at the heaviest, asphalt that is used for roads.

A special type of reservoir is important in and around the Gulf of Mexico. Salt domes rise from a layer of salt that was deposited at the base of the thick sequence of sediments that fills the Gulf and surrounding area. The salt is capable of flowing and is less dense than the overlying sediments after they have been compacted by burial. Thus the salt rises as domes (fingers) until it reaches sediment that is less compacted and consequently less dense than the salt (Box 2-2). Reservoirs commonly form around the margins of salt domes because the salt is impermeable to oil (Figure 2-6).

Since about 2010, worldwide efforts are being made to extract oil and gas directly from rocks that used to serve only as source rocks for oil and gas reservoirs. These efforts are based on techniques of enhancing recovery from oil wells by improving permeability in reservoirs ("secondary recovery"). The technique consists of ramming fluids and chemicals into rocks to increase pore spaces and improve permeability. It is known as "fracking," a contraction of hydraulic fracturing (see later in this chapter).

Box 2–2. Avery Island

Avery Island is not really an island. It is one of five hills that rise above the flat coastal plain of southern Louisiana. The elevation is caused by a salt dome that has risen close to the surface. An elevation of 153 feet above sealevel makes it possible to grow agricultural crops, particularly peppers. Mining the salt and growing the peppers make Avery Island the home of Tabasco sauce.

World production of oil is about 90,000 barrels/year. Although barrels that hold 42 gallons are seldom used now, oil is still sold in units of the 42-gallon barrel originally established by Standard Oil Co. Production of oil is very unequally distributed. The Organization of Petroleum Exporting Countries (OPEC) contains many of the major producing countries. It attempts to set the worldwide price of oil and is partly successful because of the dominance of Saudi Arabia. OPEC countries and their oil production in terms of barrels per year are:

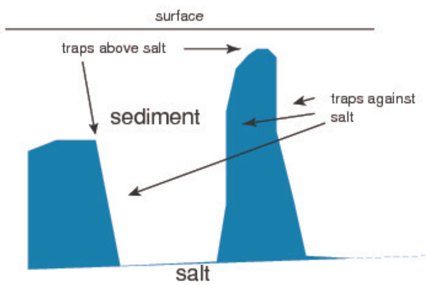


Figure 2-6. Salt domes formed by salt rising from layer of salt at base of sequence of sediments.

- Saudi Arabia 11,546
- Iraq 2,967
- Kuwait 2,797
- UAE 2,713
- Nigeria 2,524
- Venezuela 2,489
- Algeria 1,875
- Angola 1,872

- Iran 1,649
- Qatar 1,579
- Libya 1,483
- Ecuador 284

Many non-OPEC countries are also major producers. They include:

- USA 11,102
- Russia 10,397
- China 4,416
- Canada 3,854
- Mexico 2,936
- Brazil 2,652
- Norway 1,902
- Britain 999
- Colombia 969
- Azerbaijan 944
- Argentina 739
- Malaysia 634

U.S. Oil Situation

Statistics for oil production, consumption, and import are from the U.S. Energy Information Administration (EIA) for 2011. The EIA reports production in terms of thousand barrels per day. Production of oil within the U.S. is very uneven. Major producing states of crude oil (Box 2-3) and their production in terms of annual thousand barrels per day are:

- Texas 1,971
- Federal offshore 1,267 (mostly Gulf of Mexico)
- North Dakota 663 (Box 2-3)
- Alaska 525 (almost entirely North Slope)
- Oklahoma 245
- Colorado 132
- Louisiana 193
- Kansas 119

The U.S. relied on net imports (imports minus exports) for about 45% of the petroleum (crude oil and petroleum products) consumed

Box 2–3. Williston, North Dakota

Williston was a sleepy little town until people discovered oil and gas in Williston Basin in the 1930's. The basin covers northwestern North Dakota, parts of Montana and parts of southern Canada.

The basin contains 15,000 feet of sediments at its deepest part, which is near Williston. The basin is filled largely by sediments deposited 500-200 million years ago. These sediments lie on a "basement" of granitic rocks along the "Trans-Hudson orogen," a belt of rocks deformed about 1.9 billion years ago that separates the Canadian Shield.

The Bakken Formation in the Williston basin is a shale that lies between two sequences of limestone. Approximately 400 million years old, The Bakken is covered by 10,000 feet of sediment. The Bakken has a maximum thickness of 500 feet.

No significant oil production in Williston occurred until after World War II. Initially, the Bakken was ignored as a reservoir for oil because the rock was too "tight" for oil to flow freely to a well. Improved fracking techniques encouraged development of oil and gas resources from the Bakken.

Now, organizations have decided that the Bakken contains enormous reserves of both oil and gas. All of the oil contains both natural gas (methane, ethane) and heavier molecules (propane, butane) which can easily be marketed as natural gas liquids. The production of these gases is expected to increase as the wells age. Currently, the gases are burned off, but companies are preparing infrastructure for the gases to be captured and marketed.

All of this economic potential created by the Bakken has caused an avalanche of people moving to Williston and surrounding areas. The population of Williston was about 12,000 for many years, but it jumped to more than 15,000 in a few years and is still growing. The influx has outstripped available housing, and trailer homes are common. The town has had to import teachers and set up temporary buildings at schools. Emergency expansion has been required for medical facilities and police stations. This economic boom in Williston is sustainable only if oil and gas prices remain high.

in 2011, which is lower than the imports in previous years since imports reached a peak in 2005. About 22% of U.S. imports of crude oil and petroleum products came from the Persian Gulf countries of Bahrain, Iraq, Kuwait, Qatar, Saudi Arabia, and United Arab Emirates. The percentages of imports into the U.S. in 2011 from various countries are listed below:

- Canada 29%
- Saudi Arabia 14%
- Venezuela 11%
- Nigeria 10%
- Mexico 8%

Fracking

In 2010 the EIA recognized the enormous difference that fracking would make to the U.S. energy supply. An EIA map published in 2009 shows the areas of the U.S. opened to oil and gas production (Figure 2-7). If we use fracking to produce oil, we open huge resources in the U.S. The largest is the Marcellus-Utica complex of western New York, western Pennsylvania, eastern Ohio, and West Virginia. Numerous reservoirs are scattered west of the Marcellus-Utica throughout the Midwest and into the Rocky Mountains. Three major ones are in Texas: Barnett in the north, Eagle Ford in the south, and parts of the Permian basin in the west. The farthest west is the Mancos shale in the Uinta basin of eastern Utah. The potential production is so impactful that the International Energy Agency (IEA), headquartered in Paris, predicted that by 2020 the U.S. would overtake Saudi Arabia and become the world's largest producer of oil.

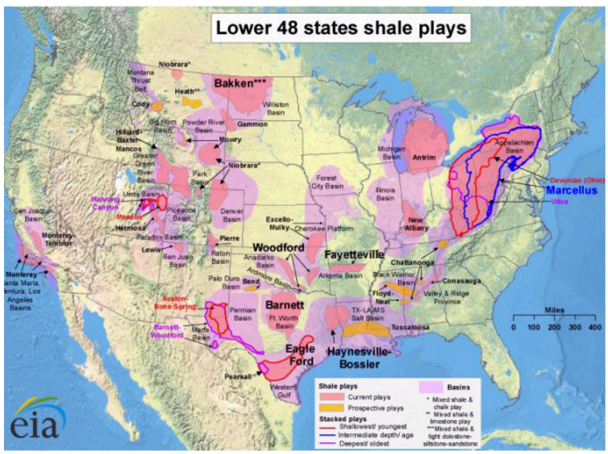


Figure 2-7. U.S. resources opened by fracking (via EIA).

Fracking has drawn a lot of opposition. The oil and gas industry has been careless in some of its early attempts at fracking. In some locations, these efforts have released fracking fluid (water and various chemicals) into ground water. In addition, some of the released gas has not been contained and also infiltrated the ground water. People who find that they can set fire to water coming from their faucets are particularly irritated.

Clearly, proponents of fracking must improve their methods in order to develop a successful industry.

Box 2–4. Michael Faraday

The design of all electricity-generating plants was discovered in 1821 by Michael Faraday, almost by accident. As he had throughout his life, however, Faraday immediately grasped the significance of his achievements and went on to design the basic elements of power generation.

Born in 1792 to a poor family, Faraday entered a 7-year apprenticeship to a bookbinder when he was 13. This ended his formal education, and Faraday never understood mathematics beyond basic algebra.

Faraday's efforts to educate himself improved when he was given tickets to attend lectures by Humphrey Davy, noted chemist and member of the Royal Society. Davy was impressed with Faraday and hired him as both a lab assistant and valet. This gave Faraday a lab to work in and an opportunity to meet other scientists.

Faraday gradually became more independent of Davy, although Davy opposed this. Ultimately, Faraday had his own lab and own income. He then began to concentrate on the relationship between electricity and magnetism.

One day in 1821, Faraday had a coil of wire and a magnet on his lab bench. Nothing happened until Faraday accidentally moved the magnet. Then there was a sudden pulse of electricity in the wire. The electric current resulted from movement of the magnetic field. Faraday figured out that electric currents were "induced" when wires passed through magnetic lines of force.

From that discovery came fame for Faraday and four equations written by James Clerk Maxwell to describe electromagnetism mathematically, (which Faraday couldn't do).

Electricity

Electricity is a means of converting the energy in a source to a more usable form and transmitting it elsewhere. There are several ways of designing generators, but they all work on the same basic principle: electricity is generated when conducting wires pass through magnetic lines of force (Box 2-4). This "induction" requires rotation and power plants use various sources of energy to cause this rotation.

One simple method of causing rotation is to let water behind a dam flow through a turbine (Figure 2-8). Turbines can also be run by steam escaping from geothermal sources (Figure 2-9) or by wind (Figure 2-10).

Figure 2-8. Dam on Columbia River, British Columbia. Turbines in face of dam.

In most power plants, rotation is caused by steam from boiling water. Several energy sources can be used to boil this water, and much of the environmental concern about electricity involves these energy sources. The World Nuclear Agency (WNA), headquartered in London, reports the fuels used for electricity generation by different countries. Most developed countries use a roughly equal mixture of hydropower, coal, gas, and nuclear energy. Two countries are exceptions: Canada generates much of its electricity by hydropower, while China relies almost exclusively on coal for its enormous generation of electricity.

Figure 2-9 (left). Geothermal steam in Kenya rift.
Figure 2-10 (right). Green Mountain Wind Farm, Fluvanna, Texas. (Wikimedia Commons)

MODERN POWER PLANTS

Nuclear reactors

Natural uranium, when mined, is 99.33% ^{238}U and only 0.7% ^{235}U. The ^{235}U is more reactive than ^{238}U, and natural uranium must be "enriched" to 3% ^{235}U before it can be used in a reactor. Both isotopes of uranium have identical chemical reactions, and they are separated by conversion to UF_6 gas. As gases, the hexafluoride compounds of the two isotopes have slightly different densities, and they can be separated by centrifuging. The enrichment must yield at least 10% ^{235}U in order to make nuclear weapons, which means that reactors cannot explode.

The reactor core with the enriched uranium is active enough to sustain a "chain reaction," with each released neutron producing more than one neutron when it collides with a uranium nucleus. The chain reaction continues until enough fission products have accumulated in the core to stop the reaction. At this time, the material in the reactor core is nuclear waste and must be stored (Chapter 6). Exception to this storage is partly made for reactors that are designed to produce large amounts of ^{239}Pu. The plutonium from these "breeder" reactors can also be used as a reactor fuel. Breeder reactors, however, are illegal in the U.S. because of the fear of producing plutonium that might be used by terrorists.

Production of enriched uranium for reactors leaves a large quantity of "depleted" uranium. This uranium has such a low radioactivity that it is used simply as a strong metal for industrial uses. One use is armor for military vehicles.

U.S. situation

The EIA reports the types of energy sources used for generating electricity (Box 2-5). The nationwide summary for 2011 is as follows, with all data in thousands of megawatt-hours, and minor contributors omitted:

- Total 4,100,656
- Coal 1,733,450
- Oil 30,182 (¼ of last 10 years)
- Natural gas 1,013,689 (doubled in last 10 years)

• Nuclear	790,204	
• Hydropower	319,355	
• Solar thermal/photovoltaic	1,816	(tripled in last 10 years)
• Wood/wood-derived fuels	37,449	(not used in most plants)
• Geothermal	15,316	
• Biomass besides wood	19,222	(not used in most plants)

The EIA also reports increase in the demand for electricity in the summer because of the use of air conditioners (Box 2-6).

Box 2-5. AC or DC?

When Thomas Edison decided to electrify New York City in 1882, he and his advisors decided to distribute direct current (dc) from their generating plant. This method of distribution worked well for short distances and small groups of users. Over long distances, however, direct currents became unstable and lost power. Those defects strengthened the arguments of people who wanted to distribute electricity by alternating current (ac).

One of Edison's opponents was Nikola Tesla, who had come from Serbia to work with Edison. In addition to disagreeing about the methods of power transmission, Tesla felt that Edison was stealing his ideas about electricity and magnetism. Fortunately, Tesla was soon hired by George Westinghouse and given the task of distributing electricity from power plants.

All power plants in the world now distribute power by ac transmission. The frequencies and voltages, however, are highly variable. The U.S. has now settled on 60 cycles per second (60 hertz) and 220 volts, with changes made by local transformers. This standardization was not achieved until about 1930 and followed a time when power plants distributed at a wide variety of frequencies and voltages. Britain and most other countries in northern Europe have standardized on 50 hertz.

Tesla, himself, was an interesting person. Now that the term as been invented, he is referred to as a geek. He achieved this status by holding more than 100 patents in electricity and magnetism. In order to achieve this, however, Tesla worked all the time. He had no social life and never married.

Box 2—6. Willis Carrier

Armed with a degree in engineering from Cornell, Willis Carrier found a job that paid $10 a week. He also had an idea.

Carrier had developed an air conditioning machine that could cool individual houses, offices, and small businesses. His air conditioner worked because adiabatic expansion of a gas causes cooling (Figure 2-11).

The problem was that Carrier's air conditioning units were expensive. They cost too much for ordinary houses. Schools were not air conditioned and only some businesses justified the expense. This was because they had to keep their products cool or it made their employees more efficient. Movie theaters advertised that they were air conditioned as a lure to attract customers.

By the 1950's, these restrictions began to disappear. Owners of houses bought window units and, then, central air conditioning units. By the 1960's, all offices, stores, schools, and places of entertainment had central air conditioning.

Wills Carrier would have been pleased, but he died in 1950.

Conservation and Renewable Energy

Ideally, all people in the world will learn to use only energy sources that are renewable. This lifestyle requires less consumption of energy in addition to development of different energy sources. Some of the problems are summarized below.

Conservation

The idea of reducing our energy usage seems simple. People, particularly in the U.S., use too much gasoline by commuting long distances between their residences and their places of work. The problem is that most people work in cities, where rents or costs of ownership of residences are much higher than they are where people actually live, such as a distant suburb. The use of gasoline can be reduced by such simple means as car pooling and riding buses and trains. Americans, however, are reluctant to give up driving their cars.

Another way to conserve energy is eliminate air conditioning in homes. Americans did not use air conditioners in homes until about the 1950's (Box 2-6). We can save much of our production of electricity if we are willing to live as we did before 1950.

Biomass: Plants, including trees, are renewable. They will never be used up, provided that we do not burn them faster than they grow. This very simple restriction, however, is inadequate to prevent biomass consumption from being harmful to people. Most of our present use of biomass for energy consists of conversion of corn to ethanol for gasoline. This use of corn increases its price and reduces its use as a food for people (see Chapter 1).

Geothermal power: The interior of the earth continually generates heat that flows out through the surface. In most places, this heat flow is small, and efforts to use it must be carefully designed.

Hydropower: The maximum amount of energy that can be produced from water is the total potential energy of water above sea level. The U.S., and several other countries, have nearly reached this limit. Canada has unused hydropower, some on its Arctic islands, and Iceland and Greenland have excess capacity.

Solar power: The earth receives more energy from the sun than is used by all human activities. There are two ways to harness this energy: 1) focus mirrors so that they cause water to boil and run a turbine and 2) generate electricity directly by photovoltaic activity. Photovoltaics (PV) are the principal method used (Figure 2-11).

A photovoltaic panel consists mainly of silicon (Si) metal "doped" with phosphorus (P) and boron (B). Both P and B fit into the Si lattice, but P has 5 valence electrons and B has 3, compared with the 4 valence electrons of Si. Migration of extra electrons to "holes" near B sites generates electrical current.

Figure 2-11. Solar cells, Germany. Photo by Eclipse.ax via Creative Commons.

Solar power does not produce electricity at night or when the sun is obscured during the day. For this, and many other reasons, it is necessary to design batteries or some other method of storing electricity.

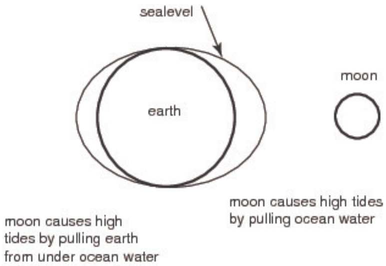


Figure 2-12. Tides. High tides occur close to the moon by sea water pulled toward the moon and opposite the moon by sea water rising over solid earth pulled toward the moon.

Tidal Power: The daily rotation of the moon around the earth causes high tides twice a day (Figure 2-12). This energy is enormous, but methods for using it have not been developed (Box 2-7).

Box 2–7. Bay of Fundy

The Bay of Fundy looks like a gash between New Brunswick and Nova Scotia. Its tide range of 20 feet is the largest in the world (Figures 2–13 and 2–14). People must leave plenty of length on anchor ropes when they moor boats to prevent the boats from turning over when the tide rises or falls. The tide comes in so fast that people walking in the bay at low tide have drowned.

The Bay of Fundy extends to higher elevations at the head of the bay. High tides there put an inch or two of water on grassy meadows.

Various methods have been used to produce electricity from the tidal energy expended in the bay. They include trapping water behind dams and placing turbines on the bottom of the bay. None of the methods have been acceptable to environmentalists.

The Bay currently produces no electricity.

Figure 2-13. High tide in bay of Fundy.

Figure 2-14. Low tide in bay of Fundy.

SUGGESTIONS FOR FURTHER READING

Bodanis, David, 2005, Electric Universe: The Shocking True Story of Electricity Crown.

Deffeyes, Kenneth, 2002, Hubbert's Peak; the Impending World Of Shortage. Princeton.

Rhodes, Richard, 1986, The making of the Atomic Bomb. Simon and Schuster.

Yergin Daniel, 2008. The Prize: The Epic Quest for Oil, Money & Power. Simon and Schuster

Yergin, Daniel, 2012, The Quest; Energy Security and ef Remaking of the Modern World. Penguin

TOPICS FOR DISCUSSION

- Should we stop burning coal?
- Should we stop air conditioning homes?
- Should we raise gasoline prices so people drive less?
- Should we use more nuclear power for our electricity?
- Should we depend on photovoltaics for more of our electricity?
- Should we encourage fracking?
- Should we develop tidal power?
- Should we make alcohol from non-edible plants?

CHAPTER 3
CLIMATE

Why is the earth's surface warm enough to support the animals and plants that live on it? We address that question in the first part of this chapter, proceed to the history of the earth's climate, and finish with the problem of climate change.

THE EARTH'S ATMOSPHERE

Nature of the atmosphere

We begin by discussing the nature of the earth's troposphere, which is the lowest part of the atmosphere and contains more than 80% of the atmosphere. It has a composition of:

- N_2 78%
- O_2 21%
- Ar 0.93%
- H_2O (vapor) variable (<5%)
- CO_2 0.035% (now)

The abundance of the major gases has been approximately constant for the past two billion years. The atmosphere of the earth before two billion years ago was reducing rather than oxidizing. At that time, however, ferrous iron that had been soluble in seawater was converted into insoluble ferric iron, which gives a reddish color to much of the earth's land surface. The transition was probably caused by release of oxygen into the atmosphere by blue-green algae (cyanobacteria).

The troposphere is a zone in which temperature decreases as elevation increases. The reason is that pressure decreases with increasing elevation and the air expands adiabatically because it has no way to exchange heat with its surroundings. Thus, the work done by the rising air as it expands is powered solely by withdrawal of heat from the air itself. The resultant cooling leads to the term "lapse rate."

Let lapse rate = $-dT/dz$ and assume it is constant where T is temperature and z is altitude. For adiabatic processes, $W = dE$ (or dU in some terminology), $dE = c_v dT$ and $W = pdV$.

In a simple system, assume one mol (n=1) of an ideal gas in which pV=RT and $R = c_p - c_v$:

$$pdV = -Vdp + (c_p - c_v)dT$$

Therefore, if W = dE, then:

$$pdV = -Vdp + (c_p - c_v)dT + c_v dT = -Vdp + c_p dT$$

In a system in which T and p vary with z, for a unit number of mols (n=1), the gas law and first law of thermodynamics for an adiabatic system yield:

$$c_p dT = pdv - Vdp/dT/dz$$

Furthermore, pressure is caused solely by overlying atmosphere. Thus:

$$dp = -\rho gdz$$

where g is gravity and ρ is the density ($\rho = 1/v$ for n=1). Combining equations and assuming dT/dz is constant leads us to:

$$dT/dz = g/c_p = \text{approximately } 10°\text{C/km (Figure 3-1)}$$

This rate of cooling is valid only for dry air. Moist air can produce heat by condensation of the water, and the resulting lapse rate is lower (which is why humid air is warmer than dry air).

A more complete, and slightly different, derivation of the dry lapse rate is on the web at the location shown below. Both it and the derivation outlined here start with the ideal gas law and the first law of thermodynamics.

Website: //http://pdsatmospheres.nmsu.edu/ education_and_outreach/encyclopedia/adiabatic_lapse_rate.htm

Figure 3-1. Snow line in Colorado separates below-freezing temperatures above from above-freezing temperatures below.

Greenhouse effect

We continue with the concept of black-body radiation and proceed to spectral absorption. Black-body radiation and spectral absorption together are popularly known as the "greenhouse effect."

Black-body radiation refers to the ability of an object to absorb incoming radiation and radiate the energy back at the temperature of the object. There is no ideal black body, but the earth approximates one. The earth receives high-energy radiation from the sun plus a trivial amount of cosmic radiation. Some of this radiation is reflected back into space from the earth's atmosphere and by snow and ice. The percentage reflected is referred to as the "albedo," which is currently about 33% for the earth as a whole.

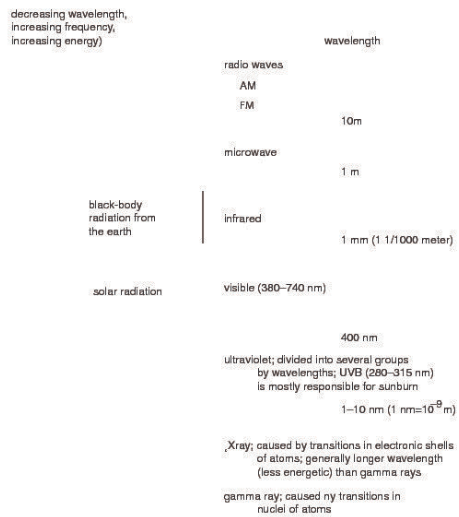


Figure 3-2. Spectrum of radiation. Wavelength and frequency are inversely related, with energy of wave packets proportional to frequency. Solar radiation centers around visible light, while earth is mostly infrared. No specific border is shown between X-ray and gamma-ray fields because the radiation is produced by different processes. Only part of the ultraviolet spectrum is dangerous.

This amount of reflectance means that about 2/3 of solar radiation is absorbed by the earth and radiated back into space at the temperature of the earth's surface. The actual temperature varies from place to place, and the average is commonly cited as 25°C (77°F). This temperature is also equal to 298 K (K stands for Kelvin, who developed a temperature scale starting at absolute zero, –273°C).

The wavelength of radiation forms a spectrum that depends on temperature according to Wien's displacement law, which is:

$$\lambda_{peak} \times T_{emission} = 2.898 \times 10^{-3} \text{ m}$$

where λ_{peak} is the peak of the emitted radiation spectrum.

The sun, with a surface temperature of about 6,000 K, and the earth (300 K) have very different emission spectra (Figure 3-2). The peak of radiation emitted by the sun is about 419 nanometers (nm = 10^{-9} m). Radiation emitted by the earth peaks at about 9,700 nm, in the infrared. Furthermore, the short wavelengths of energy from the sun indicate that packets of solar radiation (photons) are very energetic. That energy can be derived from the fact that the radiation is travelling at the speed of light (292,792,482 m/sec). Thus:

$$\lambda \times \eta = 292{,}792{,}482 \text{ m/sec}$$

where η is the frequency of the radiation.

Max Planck (Box 3-1) is widely regarded as the originator of quantum theory, and he assigned energy to the quanta of radiation according to the equation

$$E = h \times \eta$$

where h is Planck's constant. In different units, $h = 6.626 \times 10^{-34}$ kgm^2/sec = 6.626 J x sec, where J is joule (see chapter 2).

Box 3—1. Max Planck

Max Planck was born in Kiel, Germany, in 1858. His father was a professor of law at the local university, but Max was more interested in science. His first professional work was in heat and thermodynamics. He broadened his interest and won the Nobel Prize in Physics in 1918 for the development of quantum mechanics.

Although he did not join the Nazi Party, Planck decided to remain in Germany even after Hitler came to power. His decision to remain a loyal German turned out badly for his family. Planck's son, Erwin, resisted Nazism and was shot in January, 1945, just 4 months before Germany surrendered.

Regardless of wavelength, energy radiated from the earth would pass directly into space if the earth did not have an atmosphere. The moon, for example, has no atmosphere, and its surface temperature is essentially that of space.

Main gases that absorb in the infrared and their principal absorption wavelengths in nanometers are shown below. The wavelength at the top is the strongest absorber. The wavelengths listed below aren't single peaks. They are simply the most effective absorbers among numerous wavelengths, including multiples:

- **Water vapor:** the strongest absorption is at 6,300 nm, associated with rotation. Three absorptions are associated with the two hydrogen-oxygen bonds. They represent stretching of one or both bonds and changes in the angle between them. Principal absorptions are at:
  - 2,734 nm
  - 2,876 nm
  - 2,162 nm
- **Methane**: the strongest absorptions are for rotation of the molecule at:
  - 8,700 nm
  - 8,630 nm
  - 8,400 nm
- **Carbon dioxide**: the CO_2 molecule is mostly linear, and most of the energy absorbed gives greater activity to the carbon–oxygen double bonds. When these bonds are highly activated, the molecule becomes slightly non-linear and develops a larger rotational momentum.
  - 160,000 - 140,000 nm
  - 4,400 - 4,300 nm

The term "greenhouse effect" comes from the similarity between the action by the earth's atmosphere and by the glass in a greenhouse. In both cases, solar radiation is passed to the inside, which remains warm because infrared radiation cannot escape to the outside.

Cyclical processes

It is very important to recognize cyclical (periodic) processes. They can be predicted, and non-cyclical ones generally cannot. There are several methods for determining cyclicity. One of the first is Fourier analysis (Box 3-2).

The use of Fourier analysis was initially hampered by the long time required even for computers to calculate Fourier frequencies. This problem was largely overcome in 1965 when Cooley and Tukey developed the Fast Fourier Transform (FFT), which calculates the frequencies that contribute to a data set, along with their importance. Now, FFT programs can be downloaded from numerous websites, many of them free.

> **Box 3–2. Jean Baptiste Joseph Fourier**
>
> Joseph Fourier, as he preferred to be known, was clearly a genius. Born in 1768 and orphaned shortly afterward, he somehow got an education in mathematics. Lacking an adequate employment opportunity in France and briefly imprisoned during the Revolution, he accompanied Napoleon to Egypt in 1799. There he was appointed administrator for Lower Egypt.
>
> After the French were thrown out of Egypt, Fourier returned to France. Still a loyal supporter of Napoleon, Fourier was finally appointed to positions where mathematics was important. By this time, he had acquired significant opposition from other French mathematicians. They managed to prevent Fourier from publishing any of his ideas in English during his lifetime.

Two major problems arise with FFT analysis. One is that data sets should be equally spaced in time or position. The second problem is that the number of entries must be a power of 2.

Other methods for determining frequencies have been established. Four of them, including Blackman and Tukey's version of FFT, are described on the web at www.atmos.ucla.edu. They include the following, with descriptions quoted from the Atmos website:

- **Blackman-Tukey Correlogram Analysis**: the correlogram constructs an estimate of the power spectrum using a windowed fast Fourier transform (FFT) of the auto correlation function of the time series. It was developed by Blackman and Tukey (1958) and is based on the Wiener-Khinchin theorem, which states that if the Fourier transform of a series g(t) is G(w), and if the auto correlation function of the series is R, then the Fourier transform of R is $|G(w)|^2$ or the power spectrum of g. The resulting power-spectrum estimate is called a correlogram.
- **Maximum Entropy Spectral Estimates**: given a stationary time series X, and its first M auto-correlation coefficients ϕ_X, the purpose of MEM is to obtain the spectral density P_X by

determining the most random (i.e. with the fewest assumptions) process, with the same auto-correlation coefficients as X. In terms of information theory, this is the notion of maximal entropy, hence the name of the method.

• **MultiTaper Method**: MTM attempts to reduce the variance of spectral estimates by using a small set of tapers rather than the unique data taper or spectral window used by Blackman-Tukey methods. A set of independent estimates of the power spectrum is computed by pre-multiplying the data by orthogonal tapers.

• **Singular Spectrum Analysis**: there are three basic steps in SSA: 1) embedding the sampled time series in a vector space of dimension M, 2) computing the M x M lag-covariance matrix C_D of the data and 3) diagonalizing C_D.

Coriolis effect and Hadley cells

The atmosphere is not firmly tied to the earth (Figure 3-3). Consequently the earth at the equator rotates eastward more rapidly than the air above it. This slippage generates the trade winds, which blow continually from east to west (Figure 3-4).

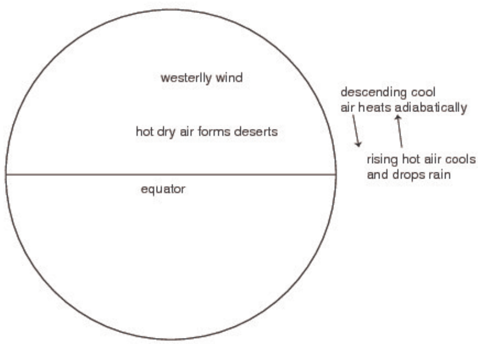


Figure 3-3. Coriolis effect and Hadley cells.

Air at the equator is hotter than air at higher latitudes because it receives more sunlight. It cools as it rises and drops rain that creates rain forests in equatorial regions. The cool, dry air forms “Hadley cells” as it moves north and south from the equator. The dry air heats adiabatically as it falls to the earth’s surface at about 30° latitude. This hot, dry air forms many of the world’s deserts centered around 20° latitude as it completes the Hadley cells by flowing back to the equator (Figures 3-5 and 3-6). These arid

Figure 3-4. St. John’s island, Carribean.

Figure 3-5. Egypt. The NIle River separates the Eastern Desert (far side of river valley) from the Sahara Desert.

Figure 3-6. Namibia. So little rain falls in the Namib Desert that this welwitchia survives by its leaves collecting dew.

conditions enhance desert conditions formed in the rain shadows of some mountain ranges (Figure 3-7).

Some of the air that descends at about 30° latitude does not return to the equator but spills toward higher latitudes. It demonstrates the Coriolis effect because it has kept some of the eastward velocity it acquired at the equator. Thus, this air is moving west to east more rapidly than the earth is rotating beneath it, and the consequence is "westerlies" that are the predominant winds in temperate regions.

Figure 3-7. Utah, in the rain shadow of the Sierra Nevada. The flat, sandy area is a playa.

Another illustration of the Coriolis effect is provided by air that moves away from the polar regions. This air is moving slower than the earth beneath it and, consequently, blows toward the west.

Hurricanes that strike the east coast of North America begin as masses of hot air that move out of the Sahara desert into the North Atlantic Ocean. They become stronger if they absorb heat. Because hot air rises, they rotate counterclockwise in the northern hemisphere. Similar storms rotate clockwise in the southern hemisphere.

Oceanic conveyor belt

The oceanic conveyor belt (Figure 3-8) begins with withdrawal of very cold water from the area bounded by Greenland, Norway, and Iceland. The cold and high salinity cause this water to sink and flow southward. The continuation of the conveyor belt past the southern tip of Africa is controversial. Some oceanographers think it follows the path shown in Figure 3-8, ultimately displacing water in all oceans. Some oceanographers think that this "meridional flow" does not occur.

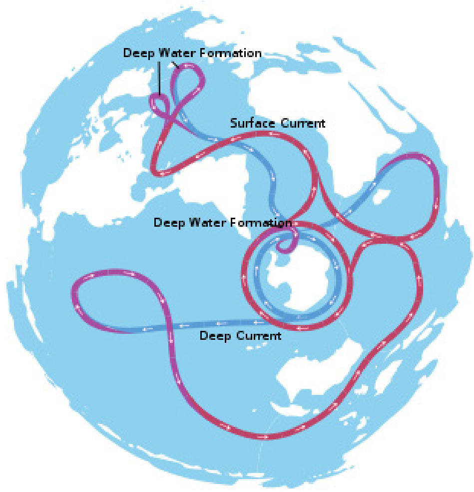


Figure 3-8. Oceanic conveyor belt from "Avsa" via Creative Commons Attribution-Share Alike 3.0 Unported.

Regardless of the complete path of the conveyor belt, it is clear that water warmed in the tropics flows northward in the North Atlantic, becoming colder as it moves north. The removal of cold water and its (temporary) replacement by warm water allows the North Atlantic current to bring warm water from the Gulf Stream past New England and northern Europe. Cutting off that warm water would make climates colder in both areas, as may have happened in 6200 BC (Box 3-3).

Atlantic multidecadal oscillation

The surface temperature of the North Atlantic Ocean fluctuates about 0.5°C between warm and cool phases. Cool periods correlate with drought in the Midwest U.S. and warm periods are times of heavier rainfall. We are currently in a warm phase, which may contribute to the strength of hurricanes. Warm and cool periods each appear to last about 50 years (Figure 3-9). All efforts to find an external cause of the oscillations have been futile, and it now seems that they are simply one of the fundamental and natural climate changes on the earth.

Box 3–3. What happened in 6200 BC?

What happened is that the warming trend that followed the Younger Dryas (ending about 8500 BC) was interrupted by a period of cold that lasted 300–400 years. This cooling was global but was particularly evident around the North Atlantic.

Bubbles in ice cores show that atmospheric methane decreased about 15%. Different temperature proxies in ice cores worldwide show temperature decreases of 1°-4°C. Sea level rose nearly 4 m.

There were few people on the earth 8200 years ago, but those who were here were profoundly affected. North Africa and the Middle East became more arid. This aridity led to the development of irrigation systems, which ultimately led to settled agricultural societies (see Chapter 1).

Why did it happen? We can't be certain, but this is a time when ice sheets that covered North America during the last major glaciation melted. Large amounts of fresh water from eastern ice sheets flowed into the Atlantic Ocean. This fresh water would have had a density less than that of the salt water in the ocean.

Enough of this fresh water in the area between Norway and Greenland could have made the water there to too light to sink. That would have shut off the conveyor belt and led to the problems that people faced for a few centuries beginning about 6200 BC.

So, what does that have to do with us? If global warming causes most of the ice on Greenland to melt, it may ne able to shut off the conveyor belt. Then people who live along the east coast of North America and in northern Europe will freeze as a result of global warming.

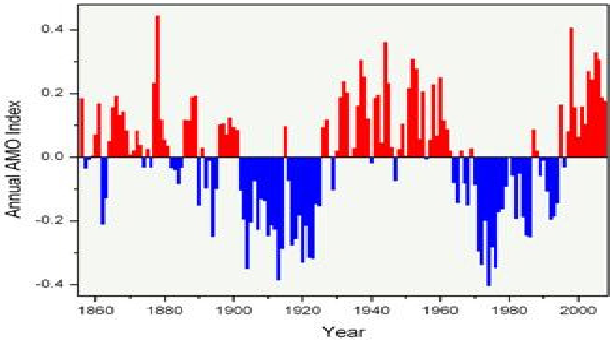


Figure 3-9. Atlantic multidecadal oscilation from NOAA.

El Nino, La Nina, and Pacific decadal oscillation

ENSO is an acronym that stands for El Nino Southern Oscillation (Figure 3-10). The term “El Nino” means the Christ child and comes from the occurrence of El Nino events near Christmas. El Nino events consist of about 1°C warming of the Pacific Ocean near the equatorial coast of South America. El Nino events alternate with La Nina events, which consist of about 1°C cooling of the water. El Ninos are associated with excess rainfall, not only in South America but as far away as southwestern U.S. Conversely, La Nina events are associated with droughts. El Nino and La Nina events commonly last a few weeks, although one El Nino apparently lasted for several decades (Box 3-4).

Box 3–4. Moche

The Moche (or Mochica) civilization predominated from about 100 AD to approximately 800 AD in the coastal region of Peru near the modern city of Trujillo. The Moche produced remarkable art, particularly in the form of ceramic tiles. They also strove to overome the aridity of their environment by building an elaborate system of irrigation canals.

All of the canals and major buildings were constructed of adobe, ordinary mud bricks. These bricks are fine when there is little rain. Unfortunately for the Moche, heavy rain began to fall about 540 AD and continued for at least 30 years (timing based on ice cores from nearby Andean glaciers). The rain rounded off the corners of most bricks and simply disintegrated some.

This destruction of irrigation systems and other parts of their infrastructure weakened the Moche and made them vulnerable to their enemies. By 1000 AD, the Moche had virtually disappeared.

We are left with the question of why 30 years of drenching rain occurred in this normally arid region. Some scientists claim that an El Nino lasted 30 years. Others think that the rain was somehow related to the enormous climatic disturbance caused by the eruption of Krakatoa in 535 AD (Chapter 5). Basically, however, we don’t know.

The El Nino-La Nina variation in the equatorial Pacific causes oscillations in water temperatures in the northern Pacific. The temperature differences between highs and lows are about 1°C. These oscillations occur over various time periods that may not be related to ENSO, and they are referred to as "Pacific Decadal Oscillations."

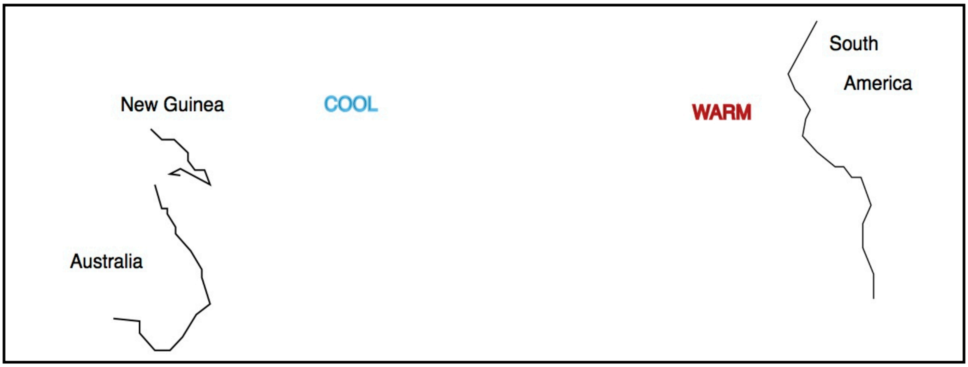


Figure 3-10. El Nino.

All efforts have failed to find periodicity in El Nino, La Nina, or Pacific Decadal Oscillations. The variations are natural but cannot be predicted more than a few months in advance. Consequently, no reason has been found for the oscillations.

ATMOSPHERE HISTORY

Variations in atmosphere composition and temperature In the past million years

Periodic variations in temperature in the past million years can be explained by variations in the earth's orbit around the sun (Figure 3-11). These orbital variations were first noticed by English scientist James Croll, but they were first described mathematically by Serbian scientist Milutin Milankovitch. Consequently, they are known as "Milankovitch cycles." Orbital variations and their periodicities include;

- **Eccentricity**: variation in the shape of the ellipsoidal path of earth's orbit around the sun; periodicity of 100,000 years. There is also a periodicity of 400,000 years that is rarely seen.
- **Obliquity**: rocking of the earth's rotational axis; angles with the normal to the plane of the ecliptic vary between 22.1° and 24.5°. The angle is currently 23.4°; the average of 23.5° leads

to the placement of the Arctic and Antarctic Circles at latitudes of 66.5° and the Tropics of Capricorn and Cancer at latitudes of 23.5°; periodicity of 41,000 years.

• **Precession:** The rotational axis of the earth has a fixed angle averaging 23.5° to the normal to the earth's plane of the ecliptic, but the direction of the axis moves periodically. Precession periodicities are 23,000 and 19,000 years. Precession combines with the "apsidal" ("perihelion") movement, in which the major axis of the earth's elliptical orbit also precesses within its orbital plane of the ellipsoid of revolution. These movements together yield a combined periodicity of about 26,000 years for precession.

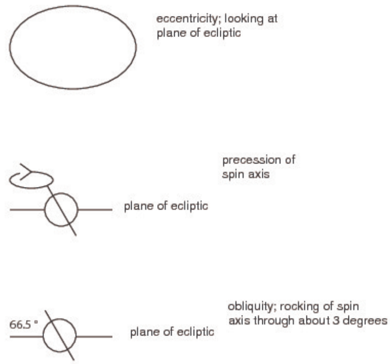


Figure 3-11. Milankovitch variations.

The composition of the earth's atmosphere is essentially constant everywhere on earth. That constancy allows us to determine the composition of the atmosphere by investigating the composition of air preserved in air bubbles in ice. The bubbles form as the ice crystallizes, either in glaciers or simply as accumulations of snow turn to ice at depth. Annual accumulations of snow are commonly capped by thin layers of ice formed during summer melts, giving

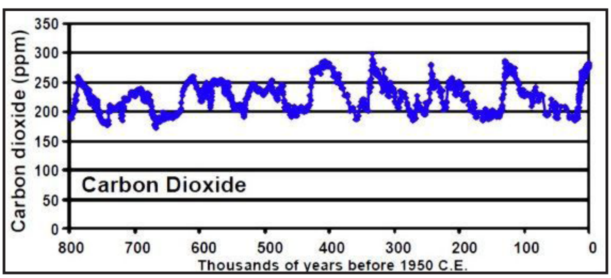
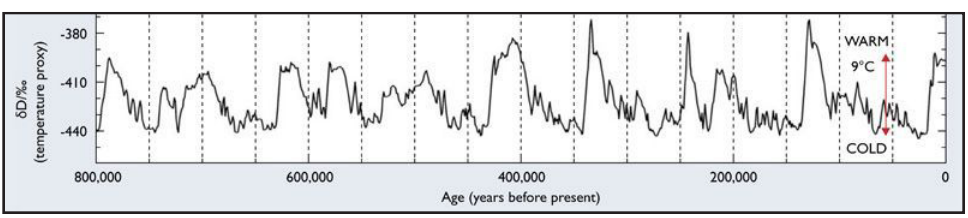
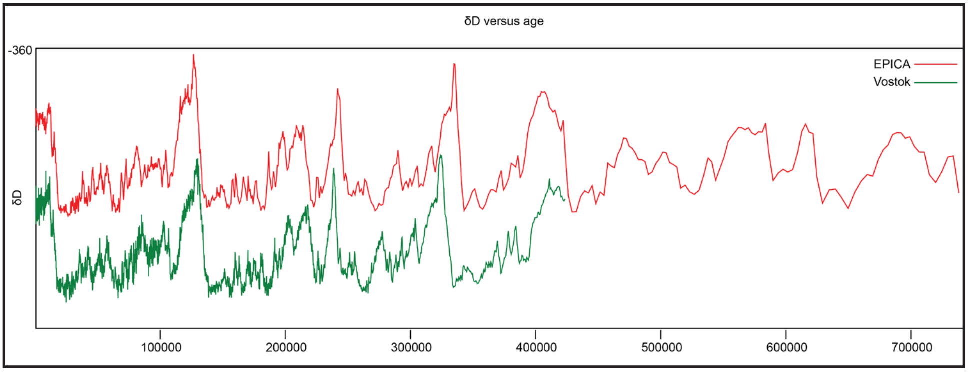


Figure 3-12A. (top) $C0_2$ raw data in Dome C core (from Carbon Dioxide Information Analysis Center, CDIAC). Jouzel et. al. 2007.

Figure 3-12B. (bottom) Delta D in Dome C core (from CDIAC). EPICA Community Members, 2004.



Figures 3-12 A-D. Show different studies of the ice core from Dome C. Data and diagrams are from the Carbon Dioxide Information Analysis Center (CDIAC). The CDIAC is an office of the U.S. Government. Consequently, all data and diagrams are in the public domain, but the CDIAC asks that people who use the data refer to the original papers in which the data are published. CO_2 data based on Jouzel, J., V. Masson-Delmotte, O. Cattani, G. Dreyfus, S. Falourd, G. Hoffmann, B. Minster, J. Nouet, J.M. Barnola, J. Chappellaz, H. Fischer, J.C. Gallet, S. Johnsen, M. Leuenberger, L. Loulergue, D. Luethi, H. Oerter,F. Parrenin, G. Raisbeck, D. Raynaud, A. Schilt, J. Schwander, E. Selmo, R. Souchez, R. Spahni, B. Stauffer, J.P. Steffensen, B. Stenni, T.F. Stocker J.L. Tison, M. Werner, and E.W. Wolff. (2007) "Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years." Science, v. 317, p.793-797. Deuterium data based on Epica community Members (2004) Eight glacial cycles from an Antarctica ice core. Nature, v. 429. p. 623–628. For comparison with Vostok, see R. Yiou, K. Fuher, L. D. Meeker, J. Jouzel, S. Johnsen, Paul Andrew Mayewski (1997) Paleoclimatic Variability Inferred from the Spectral Analysis of Greenland and Antarctic Ice-Core Data. Journal of Geophysical Research C. v. 102, Issue C12, p. 26,441–26,454. Because the ice at Dome C is actively flowing toward the South Pole, the core does not show a simple relationship between depth and age. This complexity requires that data be corrected before FFT analysis can be performed. Thanks for advice from Dr. Larry Klingenbberg of San Francisco State University.



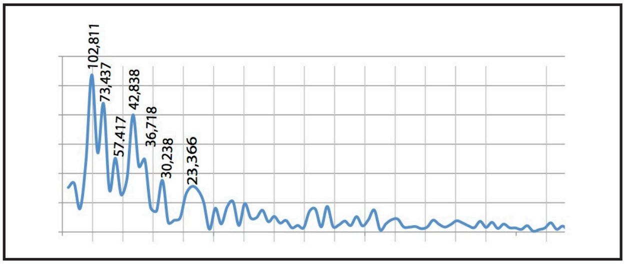


Figure 3-12C. (top) Comparison of delta D in Dome C and Vostok cores. Yiou et. al., 1997. **Figure 3-12D.** (bottom) FFT analysis of delta D measured or interpolated at 1,000-year intervals for most recent 532 years. Numbers are the times corresponding to the peaks.

investigators an opportunity to date the layers by counting back from the present. Dates of snow accumulation can be checked by dating volcanic ash layers in the ice.

The longest record of atmospheric composition and temperature spans the past 800,000 years. It comes from drilling at Dome C by EPICA, an acronym for the Eurorpean Project on Ice Coring in Antarctica (Box 3-5). Figure 3-12 summarizes studies of the Dome C core. Figure 3-12A shows the down-hole variations in CO_2 and

3-12B shows the variations in deuterium. The deuterium is used as a proxy for temperature; higher temperatures increase evaporation of D_2O from seawater and put more deuterium in the atmosphere. Figure 3-12C compares Vostok and Dome C deuterium datasets.

Box 3–5. Bocktok

Bocktok is the Cyrillic spelling of Vostok, which means "east" in Russian. Establishment of this Russian–operated research base in East Antarctica was sort of a consolation prize to Russia during the first International Geophysical year in 1956–57. It was a consolation because the Russians wanted to build a base at the South Pole, but that privilege was claimed by Americans.

The station at the South Pole was directed by Paul Siple, who had been an Eagle Scout on Byrd's first expedition to the Antarctic. Siple also coined the term "wind chill factor." Staff who spent the winter at the South Pole made the standard meteorological and magnetic measurements for the geophysical year and abandoned the station after one year. It is now completely buried in ice and has not been used again although Americans have maintained a station at the pole continually.

Vostok has also been continually occupied, and some of the staff spent their time drilling a hole in the underlying ice. They drilled to a depth of 3,600 meters and reached ice 420,000 years old. They could have drilled farther, but the base of the drill core was just above one of the hundreds of lakes on the Antarctica continent.

The drillers did not want to contaminate the lake with modern organisms or organic material, which might be contained in drilling fluids, and they stopped drilling. In early 2013, however, drillers at Vostok drilled into the lake. They let some of the water rise into the drill stem, where it froze immediately. Scrutiny of this water showed micro-organisms identical to those living today. The lake water also contained fragments of DNA that some scientists thought were different from DNA that is known today.

Vostok is on a part of the polar plateau that is higher than the South Pole. Consequently, the surface of the polar plateau is flowing into western Antarctica at a few meters per year.

Both CO_2 and D show an obvious periodicity of 100,000 years, and it is likely that the data contain shorter periodicities. Periodicities in data are commonly found by regarding the actual data sets as combinations of sinusoidal curves with different periodicities (the Fourier assumption). Figure 3-12D is an FFT analysis of the last 532,000 years from Dome C.

Peaks in Figure 3-12D clearly show the significance of major orbital variations. Peaks at 102,811 years, 42,388 years, and 23,366 years correspond to periodicities in eccentricity, obliquity, and precession. Minor peaks at 73,437 years and 36,718 years may be offsets of eccentricity and obliquity periodicities, respectively, caused by flow of the ice beneath Dome C. The origin of the peaks at 53,117 years and 30,238 years is not understood.

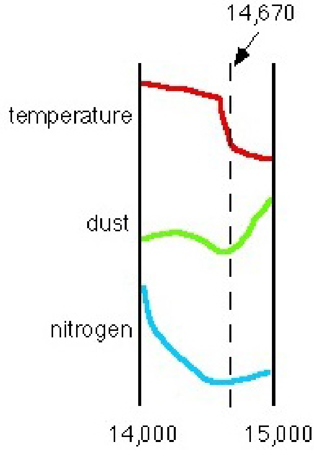


Figure 3-13. Example of rapid climate change in Greenland near the end of the last glacial period. Temperature increase of several degrees is associated with decrease in dust from non-vegetated land and increase in nitrogen from plants.

The similarity, near identity, of the periodicities in the D data with periodicities in the earth's orbit show that orbital variations control many aspects of the earth's climate. Warmer temperatures shown by higher D concentrations are apparently caused by higher solar insolation. This conclusion is supported by the variations in CO_2 concentrations. Increasing temperature decreases solubility of atmospheric CO_2 in the oceans by shifting the dissolution reaction to the left:

$$\text{Atmospheric } CO_2 = H_2CO_3 = HCO_3^- + H^+$$

Dissociation of carbonic acid in the oceans to bicarbonate and hydrogen ion makes seawater slightly acidic and puts stress on organisms that secrete calcium carbonate shells.

Temperature variations in the past 20,000 years

The past 20,000 years spans the end of the last major glacial epoch. This last time of widespread glaciation in the northern hemi-

Figure 3-14. (top left) Glacial moraines in Wyoming. Each moraine was formed during a temporary halt in the melting of this glacial tongue that extended into the valley from a mountain glacier.
Figure 3-15. (top right) Glacial erratics in Sweden.
Figure 3-16. (bottom left) Glacially disrupted drainage in Wisconsin.

sphere appears to have ended within a few decades about 15,000 years ago. Instead of a gradual warming, the end of glaciation appears to have occurred as a series of rapid changes, such as one observed in a Greenland ice core 14,672 years ago (Figure 3-13). The speed is shown partly by preservation of ^{15}N

Figure 3-17. (left) Remnant of Rhone glacier, Switzerland.
Figure 3-18. (right) Glacially abandoned Rhone valley, Switzerland.

anomalies in firn (snow/ice).

Melting glaciers that once covered continents left abundant evidence of their former existence, including moraines (Figure 3–14), erratics (Figure 3-15), and disrupted drainage (Figure 3–16). Valley glaciers also began melting back at this time (Figures 3-17 and 3-18). The disappearing valley glaciers left steep-walled sides (Figure 3-18) and waterfalls (Figure 3-19).

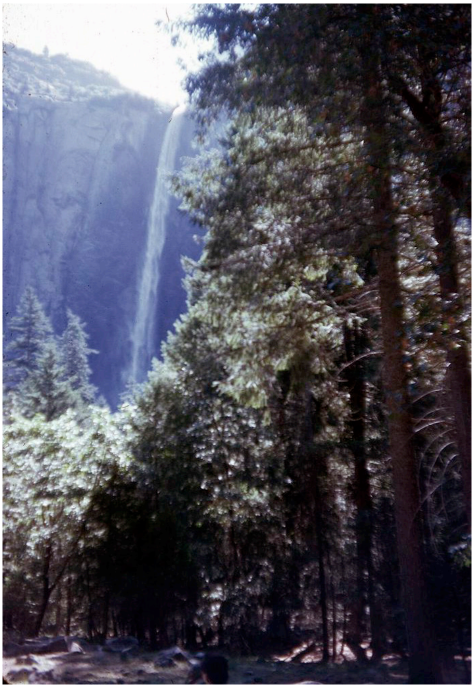


Figure 3-19. (top left) Bridalveil Falls, Yosemite, California.
Figure 3-20. (top right) Fjord in Norway.
Figure 3-21. (middle right) Islands off the coast of Finland.
Figure 3-22. (bottom right) Dryas in Iceland. The dryas are the small white tufts.

So much water was held by glaciers on land that global sea-level was nearly 150 meters lower than present at the peak of the last glaciation (Figure 3-20). Water rose as glaciers melted, forming fjords where it occupied former valleys (Figure 3–20) and islands where it covered hilly landscapes (Figure 3-21).

The end of the last major glaciation was not followed by permanent warming. The warm-up was interrupted by 1,000-2,000 years known as the Younger Dryas (Figure 3–22). It is primarily recognized in Europe, by finding pollen from the dryas plant in bogs in southern Europe. Dryas is an important temperature indicator because it grows in cold climates, particularly periglacial ones (Figure 3–22). The cause of the Younger Dryas cooling is controversial. Some geologists have attributed it to almost continual eruption of Hekla volcano in Iceland, but others doubt that an eruption could have lasted that long.

The speed of the end of the last major glaciation is supported by the speed of several other changes. At least 25 Dansgaard–Oeschger events have occurred, both before and after the end of major glaciation. Each event is a few decades long and consists of rapid warming of a few degrees followed by cooling. There have also been 6 Heinrich events. They are represented by layers of coarse sediment in Atlantic bottom sediments and presumably represent times when ice (possibly as icebergs) was released into the Atlantic and dropped its load when it melted.

Climate history of the last 2,000 years

People began keeping written records before 2,000 years ago. These records provide us with a more detailed record of climate change than is possible to obtain in older times.

The temperature difference between warm and cool periods during the past 2,000 years is not more than 2° and is probably related to variations in the amount of solar radiation. Variations were originally discovered by William Sporer and related to variation in sunspot intensity, with less radiation during periods of high activity.

Relation to sunspots probably does not apply to periods of cold weather lasting more than 100 years. Relationship of those periods, however, to periods of low solar intensity can be detected by measuring concentrations of isotopes produced by cosmic (mostly solar) rays in the atmosphere. Two of these isotopes are particularly important.

Carbon-14, ^{14}C, has a half-life of 5,780 years and is formed when cosmic rays add a neutron to the nucleus of ^{13}C. Beryllium-10, ^{10}Be, has a half–life of 1.36 million years and is formed when cosmic rays cause spallation of nitrogen and oxygen. The 14C is incorporated into all living organisms, and variation in its rate of production can be inferred from its abundance in tree rings. Variations in ^{10}Be, however, are measurable only in ice cores, either in the Antarctic or in Greenland.

The carbon and beryllium isotopes show that four cold periods occurred in the last 1,000 years: Oort minimum from 1,000 AD to 1,100 AD, Wolff minimum in the middle 1300's, Sporer minimum from the middle 1400's to middle 1500's, and Maunder minimum from middle 1600's to middle 1700's.

We can distinguish five periods of climate variation that had major effects on human history. The oldest is the Roman optimum (100 BC to 200 AD). Rome remained a local power from its founding (before 500 BC) until it expanded in 100 BC. Julius Caesar conquered Gaul (mostly modern France) in 50 BC, moved quickly into modern England, and conquered Egypt a few years later.

Caesar's successors continued the expansion, taking Jerusalem by the early years of the first century AD. After consolidating control of much of the Mediterranean, the Romans expanded eastward until they reached the Caspian Sea. Roman expansion reached its maximum about 120 AD, after which the empire mostly tried to control the area they had already conquered (Box 3-6).

Box 3–6. Hadrian's wall

After the frenzied expansion under Julius Caesar and his followers, the Romans began to think of defending what they had. Part of this was the wall ordered by the Emperor Hadrian, on which construction started in 122 AD (Figures 3-23 a and b).

Expansion continued and the Emperor Antonius tried to build a wall farther north in 468. Antonius was unsuccessful in his expansion efforts. Therefore, Hadrian's wall and the troops stationed along it remained the principal defense of Roman England against the "barbarian" Picts of Scotland.

This defense was satisfactory until the Romans found it necessary to move their troops back to defend other parts of their empire. By the early 5th century, the wall was useless, and people of all allegiances moved through it and over it at will. Some people took pieces of the wall for new construction, and some people just took souvenirs.

Figure 3-23 a. (left) Remains of part of Hadrian's wall.
Figure 3-23 b. (right) Location of Hadrian's wall.

Box 3—7. Narsarsuak, Greenland

The increasing cold forced Erik and fellow Vikings to abandon Greenland when the Little Ice Age began in the middle of the 14th century. Their descendents can now return.

The warming that has lasted since about 1850 has made Narsarsuak and nearby areas habitable. A mine (Ivigtut) for cryolite was open winter and summer from the 1850's until it closed for lack of ore in 1987. The Allies had an airbase (Bluie West One) throughout the Second World War.

After the war, the air field was used for civilian purposes. Air Iceland has two flights a week from/to Reykjavik. The former quarters for military personnel has been converted into a hotel for tourists. Tour guides lead groups around the local area and some to places farther away. Farms have opened, particularly raising horses.

On the coast is the town of Narssaq, some 50 miles from Narsarsuak and connected only by water. Narssaq has a population of about 1,500 and an economy based mostly on fishing. It also has a heliport, a hospital, schools, and shops. Remains of Viking settlements are nearby. The area near Narssaq has most of the sheep farms in Greenland.

If all of this activity seems implausible, we should realize that Narssaq is at a latitude of 60°, which is farther south than all of Iceland, most of Scandinavia, and most of Canada.

The Vandal minimum was 500 years of comparative cold. Subjugated people both inside and outside the empire rose against their Roman rulers, Visigoths were in modern Italy by 360 AD and sacked Rome in 410. Attila brought the Huns into Europe in the middle 5th century, and they withdrew eastward only after Attila's death in 453.

The Medieval warm period lasted from about 700 to 1350. William came from Normandy and took England from the Saxons in 1066. During this time, Iceland was settled and the English produced wine as far north as modern Scotland. The Vikings colonized southern Greenland near the present town of Narssaq (Box 3-7).

The Little Ice Age lasted from about 1350 to the late 1800's. It includes the Wolff, Sporer, and Maunder minima, interspersed with brief periods of warmth. Viking colonies in Greenland were immediately abandoned. Some of the cold periods were very cold. People could walk on ice across the Thames in London and from Manhattan to Staten Island in New York. Canals froze in Venice. The price of food increased in Europe, contributing to the unrest that led to the French Revolution. People migrated from Europe to North America, which was just as cold but had so much more land that the temperature was not as important.

The Little Ice Age was followed by the present period of relative warmth. In the next section, we discuss whether people are contributing to further increase in temperature.

CLIMATE OF THE FUTURE

Natural climate change

We have reviewed several types of natural climate change. With the exception of Milankovitch cycles, which are too long to have an immediate effect, all of the changes are rapid and cannot be predicted. Predictable cycles, for example, have not been found for El Nino events or the variations in solar insolation that affected life in the past 2,000 years. The abundant evidence that people are affecting climate must be evaluated with those uncertainties in mind.

Warming and sea level rise

Warming of the earth is shown both by qualitative evidence and by numerical measurements. Sea ice is disappearing so rapidly from the Arctic Ocean that the ocean may be virtually ice-free within a few decades. Disappearance of the ice is already placing stress on polar bears and may lead to their extinction. Also in the northern hemisphere, migrating bids and spring flowers are arriving earlier than they used to at the same latitudes.

The National Oceanic and Atmospheric Administration((NOAA) measures average land and ocean temperatures. Their table (below) shows differences between years in the 21st century and the land and ocean averages for the period 1991–2000. Note that all values are positive, indicating that both the land surface and the oceans are warmer than they were in the 1990's.

Year	land	ocean
• 2001	0.8084	0.4503
• 2002	0.9261	0.4908
• 2003	0.8768	0.5213
• 2004	0.8074	0.4893
• 2005	1.0407	0.5013
• 2006	0.9055	0.4799
• 2007	1.0798	0.4055
• 2008	0.8467	0.3854
• 2009	0.8582	0.4958
• 2010	1.0691	0.5026
• 2011	0.8738	0.4016
• 2012	0.9040	0.4507

Sea level is difficult to measure. Comparison with tide gauges is uncertain because of movements of the land where the tide gauges are located. The most reliable measurements are sea-surface elevations determined by NASA satellites. They show that the sea surface has risen about 0.3 mm/yr for the past 20 years (after correction of 0.03 mm/yr for isostatic subsidence). Rise in sea level is caused both by further melting of ice held on land and by thermal expansion of heated ocean water. Estimates of current rise suggest that melting and expansion are equally responsible, but the conclusion is controversial.

Greenhouse gases

Only two of the three greenhouse gases can be affected by people. Human activity can have little effect on water vapor, but the effects on the concentrations of methane and carbon dioxide are large (Figure 3-24) .

Methane and carbon dioxide have very different reactions in the atmosphere (Figure 3-24). Methane is unstable in the presence of oxygen and reacts to form carbon dioxide and water. Thus, methane can be in the atmosphere only if it is continually replenished. The sources of atmospheric methane are listed by the National Energy Technology Laboratory of the U.S. Department of Energy:

- **Natural sources**: ~40%, mostly from wetlands; the largest other source is termites
- **Human sources**: ~60%, the largest contribution is from rice paddies, with ruminants second
- Smaller contributions are from landfills and burning of fossil fuels.

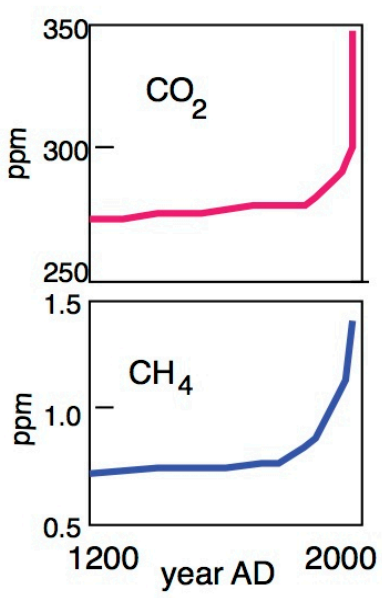


Figure 3-24. Recent changes in atmospheric concentrations of CH_4 and CO_2.

Carbon dioxide is stable in the atmosphere and is removed only by solution in the oceans and by photosynthesis. Information on carbon dioxide is provided by the Carbon Dioxide Information Analysis Center (CDIAC) of the U.S. government's Oak Ridge National Laboratory. Human activity is placing a large amount of carbon dioxide in the atmosphere (Figure 3-25),

The CDIAC recently concluded: 'Of the total emissions from human activities during the period 2002-2011, 46% accumulated in the atmosphere, 26% in the ocean and 28% on land. During this period, the size of the natural sinks have grown almost at the same pace as the growth in emissions, although year-to-year variability is large. Climate phenomena such

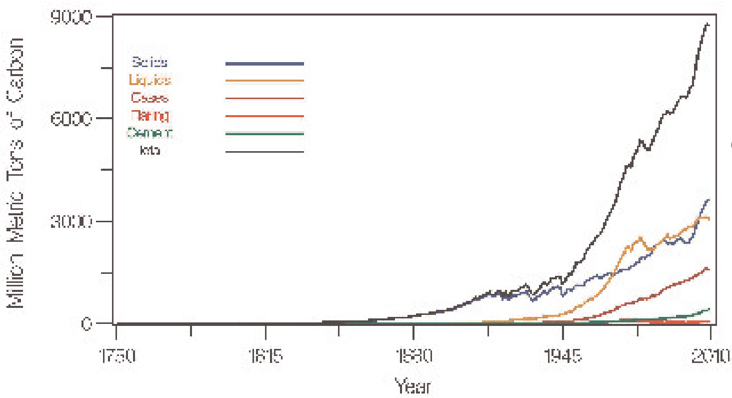


Figure 3-25. Sources of atmospheric CO_2. From CDIAC.

as the warm Southern Oscillation-El Niño can even turn the net land sink into a net source for brief periods."

This conclusion raises three important issues. One is the increase in CO_2 dissolved in the oceans despite increase in seawater temperature. The decrease in solubility at higher temperature is apparently offset by the higher partial pressure of the gas. A second issue is increased photosynthetic storage on land despite the claims that people are reducing the amount of vegetation by overforesting. The final problem is that nearly half of the released carbon dioxide simply accumulates in the atmosphere and increases the concentration (Figure 3-24).

What could/should people do about climate change?

First, we must understand the natural processes that control climate and cannot be affected by people. They certainly include variability in solar radiation and probably include oscillations in ocean temperature such as ENSO and the Atlantic Multidecadal Oscillation. About the only factor affecting climate that people have any control over is emission of greenhouse gases.

Reducing emission both of methane and carbon dioxide will be difficult. There is no way to control the methane that is released naturally. Much of the human-produced methane is from rice paddies and the herds of ruminants that are increasing rapidly to feed our increasing desire for meat. The only way to reduce methane emission is to convince people to eat less rice and meat.

Carbon dioxide poses a simpler, though larger, problem than methane. Almost all of the carbon dioxide released comes from the burning of fossil fuel, either for transportation or by industry (see Chapter 2). Coal is a particularly serious producer of carbon dioxide, and it is used by countries in the early stages of industrialization. Thus, it is necessary for industrial countries and developing countries, such as China and India to agree to reduce carbon dioxide emissions.

SUGGESTIONS FOR FURTHER READING

Barbero, Alessandro. 2008. The Day of the Barbarians: The Battle That Led to the Fall of the Roman Empire. Walker and Co.

Broecker, Wally. 2010. The Great Ocean Conveyor: Discovering the Trigger for Abrupt Climate Change. Princeton.

Diamond, Jared. 2005. Collapse: How Societies Choose to Fail or Succeed. Penguin.

Fagan, Brian. 2001. The Little Ice Age: How Climate Made History 1300-1850. Basic Books.

Hansen, J.E. 2009. Storms of My Grandchildren. Bloomsbury.

Stewart, William. 2010. Climate of Uncertainty: A Balanced Look at Global Warming and Renewable Energy. Ocean Publishing.

TOPICS FOR DISCUSSION

- Should we design a society that does not emit so much CO_2?
- Should we design a society that does not emit so much methane?
- Should we close Antarctic research stations because they provide information mostly about Milankovitch variations, which are too long to affect us?
- Should we try to force China and India to use less coal?
- Should we prepare the U.S. to face more storms?
- Should we plant more trees to absorb CO_2?

Chapter 4
Non-Energy Raw materials

The earth supplies all of our needs. In addition to food, water, and energy, these needs include all of the materials we use for construction of buildings, for operation of transportation systems, for agriculture, and for the myriad of devices we use to make our lives easier. We divide this discussion into metals and non-metals.

METALS

Base metals (lead, zinc, copper)

Lead and zinc are commonly associated in veins far from any recognizable source of mineralizing fluids. The ore minerals, galena (PbS) and sphalerite (ZnS), commonly grow as well-formed crystals in empty spaces, probably originally filled by fluid.

Most copper is produced from large bodies of porphyritic intrusive rocks. The copper is distributed at grades of 0.5% to 1.0%. Copper is generally contained in chalcopyrite ($CuFeS_2$) and cuprite (Cu_2S). Mining of these "porphyry coppers" leaves a lot of waste products, including sulfur and the other 99% of the rock that does not consist of copper minerals. Most mining is done on the surface and leaves large open pits when a mine is no longer economically viable (Figure 4-1). Some mines are economically successful largely because of metals in addition to copper. Zinc, for example, is produced from some copper mines, and the major molybdenum production in the U.S. was from a porphyry copper in Colorado.

Figure 4-1. Berkeley pit left at Butte, Montana, after mining for copper became uneconomic; NASA photo.

Copper and zinc are relatively harmless, but lead is very dangerous. Copper is used for electrical transmission wires and for numerous construction purposes. Zinc is alloyed with copper to make brass but is used primarily for zinc metal cladding. The cladding covers iron and steel and prevents rust by oxidizing to innocuous zinc oxide. Even small amounts of lead cause neurological and brain damage in people. For this reason, lead is now used almost exclusively in lead-acid batteries, such as car batteries. Former uses in gasoline and paint have been discontinued (see Chapter 6).

Iron

Most of the world's iron ores were deposited slightly more than two billion years ago. Before the accumulation of oxygen in the atmosphere, ferrous iron was soluble in the oceans. At this time, layered accumulations of silica (chert) and iron oxide formed thick sequences of taconite. The taconite can be mined (Box 4-1), but it is more valuable if some secondary process oxidizes the various iron oxides to hematite (Fe_20_3; Figure 4-2).

Box 4—1. Hibbing, Minnesota.

The Hibbing open-pit taconite mine formed one of the largest open pits in the iron-range country of northern Minnesota. As mining continued, the pit got larger and encroached on the town from three sides. The mining company and the people who lived in Hibbing realized, around 1920, that the best remaining ore was underneath the town itself. What to do?

No problem. Move the town. The central business district was moved two miles south by 1921. Mining companies paid some of the cost of relocation. Residences and some stores remained in "North Hibbing." They were gradually bought by mining companies, and the last people moved out in 1968.

Hibbing is now a town of more than 16,000 people, but it is two miles south of the original town.

Although the major production of iron ore in the U.S. has been from open pits in northern Minnesota, the first iron ore mined was near Birmingham, Alabama. The Red Mountain formation extends for 300 miles. It consists of limestone and sediments partly replaced by hematite. The iron was mined underground from the end of the Civil War until the 1950's, when the mines became uneconomic.

Figure 4-2. Open iron pit in Mesabi Range in northern Minnesota.

Steel

The simplest form of steel is just iron plus carbon. It can be made by burning a mixture of iron ore and coal. Most of the ore that isn't iron forms a mixture of CO_2 and slag, with the iron and some of the carbon remaining as molten steel that can be poured into separate containers. This molten iron can then be combined with alloying elements to produce different kinds of steel (Box 4-2).

Box 4—2. Andrew Carnegie

Andrew Carnegie was born in 1835 to a poor weaver's family in Dunfermline, Scotland. His family moved to Allegheny, Pennsylvania, in 1849, and Carnegie got a job for $1.20 per week changing spools of thread in a cotton mill. He switched to railroads as a telegrapher at $2.50 a week.

With the aid of an uncle, Carnegie became an investor. This gave him the capital to start building his fortune. He decided to concentrate on the steel industry in Pittsburgh, which ultimately led Carnegie to control of Carnegie Steel. He sold in 1901 for $492 million. The purchasers folded Carnegie Steel into U.S. Steel, which became the world's first billion-dollar company.

By this time, Carnegie was ready to devote himself to philanthropy. Among his gifts are Carnegie Hall, Carnegie Endowment for International Peace, Carnegie Endowment for the Universities of Scotland, and Carnegie—Mellon University. When he died in 1919, Carnegie had made hundreds of millions of dollars and given hundreds of millions away. Carnegie thus fulfilled one of his leading principles. The first third of life should be spent learning how to make money. The second third making money. The final third giving it away.

Steel alloy elements

Almost all elements can be alloyed with steel in various proportions and for various purposes. We restrict the discussion to the principal alloying elements.

Chromium is alloyed with steel to make stainless steel. Chromium is mined as chromite (Fe_2CrO_4) from thick bodies of basaltic intrusive rock. The U.S. has no minable resources.

Tungsten is used in alloys to make steel hard and heat-resistant. Tungsten occurs as various tungstates in veins that are mined underground. Individual mines are small, and the U.S. has few resources.

Molybdenum as an alloy gives steel approximately the same properties as tungsten. Molybdenum ores, however, are abundant in the U.S. They consist of molybdenite (MoS_2) and are mined in open pits, commonly with copper, or underground.

Box 4–3. Greenhorns

"Greenhorn" is a slang term for easterners who are new to the western U.S. It includes people who have never walked on rocks, but only on sidewalks. The federal government was responsible for hundreds, perhaps thousands, of greenhorns descending on Moab, Utah (Figure 4-3), and similar towns in the 1950s. The government wanted to develop the peaceful uses of atomic energy and offered incentives for the discovery of new resources of uranium.

These incentives brought the greenhorns west. They knew they needed equipment, so they bought it from stores that opened for the purpose of selling to greenhorns. They particularly bought ultraviolet ("black") lights because they knew that secondary uranium minerals fluoresced. Then they wandered around at night and "staked" claims where they found fluorescence. Most of the greenhorns didn't realize that scorpions also fluoresce.

The greenhorns didn't find much uranium, but their purchases helped Moab to develop from a small town to the thriving tourist center that it is today.

Titanium alloys are corrosion-resistant. Titanium is also a strong metal by itself and is used for orthopedic replacements and other places where a strong and light-weight material is needed. The mineral principally mined is ilmenite ($FeTiO_3$), and there is plenty of reserve in open pits and sedimentary heavy mineral accumulations in the U.S.

Manganese typically alloys with steel to form mangalloy, which resists abrasion and has a high impact strength. Manganese occurs as various oxides in sediments, and mining is both underground and in open pits. Although manganese is very abundant, the U.S, has no minable resources.

Figure 4-3. Moab, Utah, 1950s. Before major development.

Vanadium is mined from a large variety of deposits. Some of the major ones are by-product vanadium from magnetite. A small, but important, set of deposits was in the "uravan" district of southwestern Utah (Box 4-3). The uravan district consists of combined uranium-vanadium minerals deposited in sediments at the surface or shallow levels. Minerals are generally yellow-green and regarded as secondary uranium minerals formed by near-surface alteration of primary minerals such as pitchblende.

Nickel makes steel tougher and more resistant to corrosion. Most nickel is mined from lateritic (iron-rich) soils, but high-temperature minerals (including pentlandite, NiS) are mined underground in Sudbury, Ontario. Sudbury is clearly an impact structure, and many geologists think the nickel comes from the meteorite. The U.S. has no minable nickel resources.

Aluminum

Aluminum ores are essentially soils. They are suites of various aluminum oxides and hydroxides that, together, are referred to as bauxite. Bauxite forms soil only in tropical countries (Figure 4-4), and the U.S. has no resources. The U.S., however, smelts aluminum from imported bauxite. Because the aluminum-oxygen bonds are very strong, this smelting requires a lot of electrical energy.

Figure 4-4. Bauxite in Hungary; developed when Hungary was farther south.

Smelting is commonly aided by mixing a flux with the aluminum ore. Flux was once supplied from a mine south of Narsarsuak, Greenland (see Box 3-7). That mine at Ivigtut produced cryolite until it closed in 1967. Aluminum is used where light weight must be combined with strength. Consequently, a principal use is for airplane bodies.

Silicon

The pure silicon used in “Silicon Valley” and all computers and other electronic equipment is produced from quartz. Quartz must be heated with a reductant, usually some type of carbon, to remove the oxygen as carbon dioxide. Impurities in the silicon are kept low by using quartz and carbon of high purity and further refinement of the silicon metal if necessary. The U.S. has abundant supplies of quartz and carbon.

Gold, silver, and mercury

Gold occurs only as the metal. Because it is heavy and resists abrasion, gold commonly forms placers (Figure 4-5). The “forty-niners” in California knew that the placer gold they discovered in rivers coming westward from the Sierra Nevada must have come from source rocks (Mother lode) in the mountains. Camps set up to mine these rocks are now connected by California State Highway 49.

Figure 4-5. Sutter’s bar, California, where placer gold was first discovered.

Gold is so rare that miners rarely see any gold. This leads to very hazardous means of recovery, either from rock before it is mined or from mined rock that has been piled up but not yet processed. Gold is soluble in mercury and as a cyanide. Thus, either unmined rock or recently mined piles of rock is washed with mercury or a solution of potassium cyanide (KCN), and the gold is electroplated out of the solution.

Silver is mined from porphyry intrusions and their wall rocks. Mining is both in open pits and underground. The principal ore mineral is argyrite (Ag_2S), which smelts at a very low temperature. Silver is commonly associated with gold and lead. Mexico is the major producer of silver, and a belt of silver production extends from the Andes to Nevada. The discovery of huge silver resources in Nevada led to to the idea of basing the U.S. currency on both gold and silver (bimetallism). Resistance by people who wanted only a gold standard brought about William Jennings Bryan's speech "you shall not crucify mankind upon a cross of gold."

Although gold and silver have always been made into expensive objects, they have also been regarded as storers of value. This storage has become almost the only reason for mining gold and silver.

Mercury mines are rare, and people who use the metal make efforts to reuse and recycle it. Mercury occurs generally as cinnabar (HgS) in shallow volcanic centers (Box 4-4). Because handling liquid mercury is even more dangerous than lead, mercury has been replaced in most uses by galinstan, an alloy of gallium, indium, and tin that is liquid at the same temperatures as mercury. Thus, people can put thermometers containing galinstan instead of mercury in their mouth.

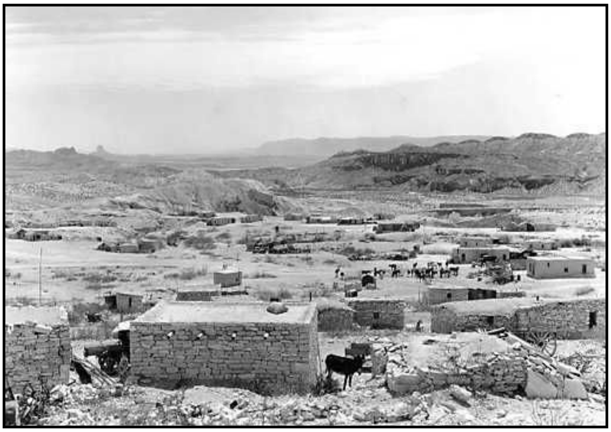


Figure 4-6. Terlingua, Texas, 1936. Photograph by George A. Grant, an employee of the National Park Service.

Box 4-4. Terlingua, Texas

When the mercury mines at Terlingua closed in the 1930s, the town had a population of 2,000 people (Figure 4-6). Almost all of them moved away, but a few people live there now. The residents call Terlingua a Ghost Town that is “a few exits past the end of the world” (Terlingua website). The Holiday Hotel is the best hotel in town--and the only one. It advertises rooms with air-conditioning but no television or telephones. The Starliight Theatre has morphed into the only restaurant in downtown Terlingua.

So, what is there to do? First we must realize that Terlingua is right next to Big Bend National Park, which offers plenty of recreation, including rafting on the Rio Grande river. Then there is simply snooping around the Ghost Town. As the website says: ”Today you’ll find a ghost town made up of decaying buildings, mine shafts, tall tales, ruins, crotchety old-timers, a three-legged dog, too much cactus, and semi-friendly rattlesnakes. It’s been slightly revitalized with rustic Texas lodgings (graciously updated), world famous chili fixin’s, an internationally acclaimed restaurant (we’re Mexico adjacent), and--perhaps most importantly--a fully operational saloon/bar.”

Twice a year Terlingua is also the home of championship chili cook-offs. Although it is not clear whether the contest continues, a fence-climbing contest happens to mimic the fence-climbing of Mexicans trying to enter the U.S.

There is also a store, the Terlingua Trading Co., that sells gifts, jewelry, and books. The store sells both in person and online.

Rare earth elements

Rare earth elements (REEs) include elements from La to Lu (lanthanides, with atomic numbers 57 to 71). They are chemically similar to both Y and Sc. All REEs have a valence of +3, and Eu also has a valence of +2. REEs commonly occur as minor components of various minerals, including monazite, xenotime, and allanite. Major deposits of REEs generally contain bastnasite, with a general formula of $(REE)CO_3F$.

Major deposits are in carbonatites. Worldwide supply of REEs used to come from a carbonatite at Mountain Pass, California. That deposit has now been supplanted by a carbonatite at Bayan Obo in Chinese Mongolia. Bayan Obo produces nearly half of the world's supply of REEs. This near monopoly lets China threaten boycotts against other countries and has sparked intense efforts to develop other sources of REEs.

REEs have become important to the worldwide economy. They are essential components of cellphones and other electronic equipment. For this reason, threats of boycott must be taken very seriously.

Lithium

Lithium has become essential to electrical operations. Most batteries are now based on lithium instead of lead. Many lithium batteries use lithium compounds as the electrolyte, but use other materials as cathodes. Recharging is not as straightforward as it is for lead–acid batteries.

Lithium is obtained from brines. Lithium ions are too small to fit In the lattices of most minerals, and they accumulate in water washed into desert valleys from surrounding rocks that contain significant amounts of lithium. This water can evaporate to form dry lakes, which contain significant amounts of lithium only if it is sufficiently abundant in surrounding rocks (Figures 4-7 and 4-8).

Figure 4-7. Badwater, Death Valley, 289 feet below sealevel.

Figure 4-8. Sevier Dry Lake, Utah. The white area is various salts dissolved from rocks in surrounding mountains and precipitated from evaporating water.

The world's major production is from dry lakes ("salars") in the Andes. Bolivia has recently discovered the largest reserves. The U.S. has imported all of its lithium, but a recent discovery of lake deposits buried beneath younger sediments in Wyoming probably gives the U.S. adequate domestic resources.

NON–METALS

The category of non-metals contains most of the material we take from the earth to run our civilization. The heaviest constructed materials are cement and concrete. This category also includes aggregate, fertilizer, water, quarry stone, gypsum, and minor materials such as asbestos and jewelry.

Cement and concrete

Cement is manufactured by heating calcium carbonate and silica together. This "calcining" develops an anhydrous calcium silicate that was originally made in England and called "Portland cement" because it had the same light gray color as the rock on Portland Bill, a peninsula in southern England. The anhydrous calcium silicate reacts with water to form a hard network of hydrous calcium silicate.

Concrete is just cement plus an aggregate that adds bulk to the mixture. The aggregate can be anything, but well-washed river gravels are ideal. Water is usually added to concrete at the production site, and concrete is sent to construction sites in trucks with continually rotating barrels. The rotation prevents the concrete from hardening until after it is poured into previously constructed molds. Concrete that needs to be especially resistant to failure is commonly poured around steel rods.

The only environmental concern about cement and concrete is the source of the calcium carbonate. Some manufacturers must import limestone (Figure 4-9). Some attempt to

Figure 4-9. Limestone used for numerous structures on Malta; Malta exports limestone for cement.

use oyster reefs, which raises the ire of people who feel the reefs should be preserved as a food source for people and an attraction for fish.

Aggregate

Aggregate is simply a loose pile of rock and dirt. It is used in the construction of features ranging from large dams to small berms that control water flow. Most of the aggregate is simply dug up at one place and dumped at another. Some aggregate, however, is sorted into different sizes. This sorting was used by John McAdam in building roads (Box 4-5).

Box 4-5. John McAdam

John McAdam was born in Ayrshire, Scotland, in 1756. Starting in 1783, he became involved in road construction. McAdam developed the concept of elevating roads above the land over which they passed. He also constructed roads by placing large fragments on the bottom and progressively smaller ones toward the top. Roads that had been graded in this way were said to be "macadamized."

People later realized that they could improve the roads by making the surfaces smoother with asphalt. They called the resulting material "tarmac." Ultimately, large areas, such as airports and parking lots, were covered by tarmac.

Covering large areas with tarmac has environmental consequences: it is impermeable to water and prevents recharge of groundwater in covered areas.

Fertilizer

The three numbers that describe fertilizer are the percentages of nitrogen, phosphorus, and potassium. Potassium is mined from evaporite deposits and added to fertilizer as KCl. Phosphate is mined from phosphate deposits and added to fertilizer as various types of phosphates. The problem has been nitrogen.

Nitrogen generally does not occur in any deposits. All nitrates and all ammonium salts are very soluble. For this reason, nitrogen is now added to fertilizer from synthetically produced ammonia, either as ammonium or after conversion to a nitrate. Before synthetic nitrogen, however, the Atacama Desert was the only reliable source of nitrogen in the world (Box 4-6).

Box 4-6. Atacama Desert

With an average rainfall of only one half inch per year, the Atacama Desert is one of the driest places on earth (Figure 4-10). Consequently, the Atacama Desert was the only place in the world that contained potassium nitrate, which was necessary for fertilizer production in the 19th century.

Bolivia owned the Atacama until 1904. At that time, a treaty ended a war between Chile and the combined forces of Bolivia and Peru. The treaty gave the Atacama region to Chile with various guarantees, never fully honored, to Bolivia. The main effect on Bolivia was cutting off access to a seaport, and Bolivia has been landlocked since 1904.

The original cause of the war was the nitrate, but it is now irrelevant because fertilizer is now made with atmospheric nitrogen. The Atacama, however, is still profitable for Chile because of the development of copper mines.

Nitrogen in fertilizer raises numerous environmental issues. Most of them center around leakage of nitrogen from the area fertilized into surrounding areas. A principal example is washing of nitrogen from fertilized agricultural land into adjacent water. Excess nitrogen in the water promotes growth of algae and other single-celled organisms in the water. Extreme growth may use up all of the oxygen in the water, a process known as eutrophication. Eutrophic water may contain so little oxygen that fish cannot live in it. Eutrophication naturally sets up confrontations between agriculturalists and members of the fishing industry. People who make their living by fishing claim that agriculturalists use too much fertilizer and/or do not prevent it from washing into rivers and ultimately into oceans and lakes.

Figure 4-10. Atacama Desert, Chile. Photpgraph by Valerio Pillar, released under Creative Commons Attribution Share Alike 2.0 Generic license.

Water

Fresh water is available from surface features such as streams and lakes and from the ground (Figures 4-11 and 4-12). In evaluating water supply, one must distinguish two kinds of landscapes. In an area with abundant rainfall, streams gain water from the ground, and people can extract water anywhere, if they do not exceed the rate of rainfall. In dry areas, rainfall is too low to raise the water table near the surface, and streams lose water into the ground.

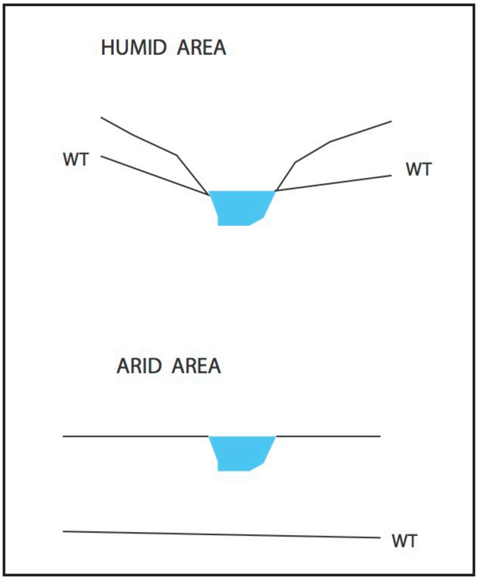


Figure 4-11 (left). Streams in humid and arid areas. In humid areas, streams flow in valleys they cut. Groundwater below water table flows into streams. Streams in arid areas are above water table and lose water to the ground. WT is water table.
Figure 4-12 (right). Water table seen in tank in Saudi Arabia.

Most of the U.S. has adequate rainfall except for occasional droughts. The southwestern part of the country, however, is arid. Therefore, water must be imported. One of the largest users of imported water is Los Angeles (Box 4-7).

Building stone

Building stone is selected for its beauty. Favorite types include granite (Figure 4-13 and 4-14) and marble (Figure 4-15). Marble is also “soft” enough to be carved and used in sculptures.

Gypsum

Wallboard constitutes many of the interior walls in U.S. buildings. It is made of gypsum interlayered with paper. The gypsum is

Box 4-7. Owens Valley

Los Angeles was a rapidly growing city at the end of the 19th century and needed water. They picked Owens Valley, just east of the Sierra Nevada, as a source.

It was a disaster. The leaders of Los Angeles claimed that they bought water rights from ranchers in the valley. Ranchers claimed that Los Angeles stole the water.

Regardless of purchase or theft, the effects on the valley were enormous. Well-watered ranches with lush grass dried up. A lake in the valley dried up and left a steamer that could no longer move to rust in the desert. A valley that once attracted new settlers began to lose population.

Some of the ranchers decided to fight back. Engineers built an aqueduct to move water from Owens Valley. Ranchers blew it up. Engineers repaired it. Ranchers blew it up again.

Finally, there is some peace between Los Angeles and Inyo County, which contains Owens Valley. Owens Valley, however, remains mostly a desert.

Figure 4-13 (top left). Baveno granite quarry in Italy.

Figure 4-14 (top right). Granite quarry in New Hampshire.

Figure 4-15 (bottom right). Marble quarry in Alpi Apuane, Italy; marble from this quarry was used by Michelangelo.

mined from gypsum deposits, and the U.S. has neither supply nor environmental problems associated with gypsum.

Asbestos

Contrary to popular myth, there is no mineral named "asbestos." The term is used for a number of minerals that can be woven and that suppress fire because they cannot burn. Most of the material used in this way is the chrysotile variety of serpentine. The other two types of serpentine (antigorite and lizardite; Figure 4-16) cannot be woven and are ignored.

Figure 4-16. Kynance Cove, England; type area of lizardite.

Another mineral commonly regarded as asbestos is a form of magnesian amphibole similar to cummingtonite.

Regarding both amphibole and chrysotile as "asbestos" is unfortunate. Amphibole is dangerous if inhaled, but chrysotile seems to be harmless. The inability, or unwillingness, of some people to distinguish different types of asbestos has led to expenditure of colossal sums of money to remove harmless chrysotile from insulation.

Jewels

Major gemstones are types of only three minerals. Diamonds are pure carbon compressed at depth and brought rapidly to the surface. Rubies are a red variety of corundum (Al_2O_3), and sapphires are blue corundum. Corundum occurs in rocks that contain an excess of aluminum, generally metamorphosed rocks originally rich in clays. Emeralds are varieties of beryl ($Be_3Al_2(SiO_3)_6$). Rubies, sapphires, and emeralds all owe their brilliant colors to trace quantities of other elements.

The four minerals regarded as "precious" stones, plus gold and silver, are supplemented by a large number of semi-precious stones. They include citrine (yellow quartz), amethyst (purple fluorite), numerous varieties of tourmaline, and opal.

Mining gems has virtually no environmental impact, but it has enormous social consequences. Gems are worth much more than the wages paid to the people who do the mining. This imbalance leads to attempts to steal gems, and mining companies develop humiliating methods to prevent theft. Furthermore, possession of gems clearly marks a person as relatively wealthy, leading to class distinctions based on money. Perhaps the most pernicious social consequences come from “blood diamonds,” which are sold to finance wars and insurgencies.

SUGGESTIONS FOR FURTHER READING

Campbell, Greg. 2002. Blood Diamonds: Tracing the Deadly Path of the World's Most Precious Stones. Westview.

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UN Industrial Development Organization. International Fertilizer Development Center. 1998. Fertlizer Manual, 3rd ed. Springer.

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TOPICS FOR DISCUSSION

- Should we ban all use of lead?
- Should we develop alternatives to iron and steel?
- Should we develop alternatives to aluminum?
- Do we use too much fertilizer?
- Do we waste water?

CHAPTER 5
NATURAL DISASTERS

Natural disasters tend to affect large numbers of people and their structures concurrently. For this reason, private insurance companies do not include them in their basic policies. We discuss this issue, starting with the problem of ground movement caused by faulting (earthquakes). We continue with ground movement not caused by faulting (mass movement). This chapter then discusses river floods and shoreline problems, provides a discussion of volcanoes, and finishes with a very brief discussion of responsibility.

Earthquakes

Earthquakes occur when two blocks of rock overcome the friction that binds them together. The movement is caused by the accumulation of deformation (strain) in the blocks before it is released by movement (Figure 5-1).

Movements within the earth generate body waves. These waves pass elastically through the earth in all directions. Waves that reach the surface can generate surface waves, which include Rayleigh and Love waves that travel along free surfaces by slightly different modes of transmission. Rayleigh and Love waves are felt by people and can cause damage.

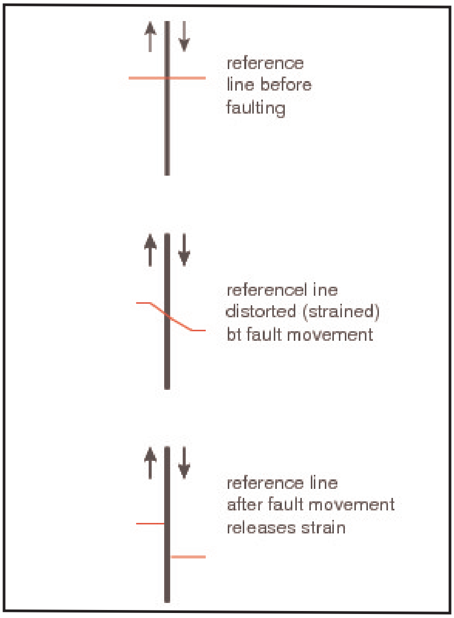

Figure 5-1. Fault.

The size of an earthquake is commonly measured in two ways: magnitude and intensity. The “magnitude” (devised by C.F. Richter) measures the amount of energy released by the fault movement. Energy is measured by the sizes of body waves at the earthquake source and numbered on a logarithmic scale with a factor of 32 between units. For example, an earthquake of magnitude 7 is 32 times as powerful as one of magnitude 6.

The source of an earthquake at depth is commonly known as the “focus” although it is rarely a single point. The point on the surface directly above the focus is referred to as the “epicenter.” It, too, is rarely a single point.

The intensity with which an earthquake is felt by people is commonly measured on a Modified Mercalli Intensity Scale (MMI)*, which is:

- **I.** Not felt except by a very few under especially favorable conditions.
- **II.** Felt only by a few persons at rest, especially on upper floors of buildings.
- **III.** Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
- **IV.** Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
- **V.** Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
- **VI.** Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
- **VII.** Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
- **VIII.** Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
- **IX.** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
- **X.** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

- **XI.** Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
- **XII.** Damage total. Lines of sight and level are distorted. Objects thrown into the air.

*Abridged from The Severity of an Earthquake, a U. S. Geological Survey General Interest Publication. U.S. GOVERNMENT PRINTING OFFICE: 1989-288-913

The USGS proposes the Rahun equations for estimating intensity at various distances from an earthquake (distance measured in miles):

- **Eastern USA**: MMI = 1.41 + 1.68Magnitude - 0.00345Distance - 2.08(log Distance)/(log 10)
- **Western USA**: MMI = 5.07 + 1.09Magnitude -3.69*(log Distance)/(log 10)

In the U.S., only California requires private insurance companies to offer earthquake insurance as a rider to their homeowners and similar policies (Figure 5-2). The price of the rider varies depending on distance from major faults, particularly the San Andreas and related faults (Figure 5-3; Box 5-1).

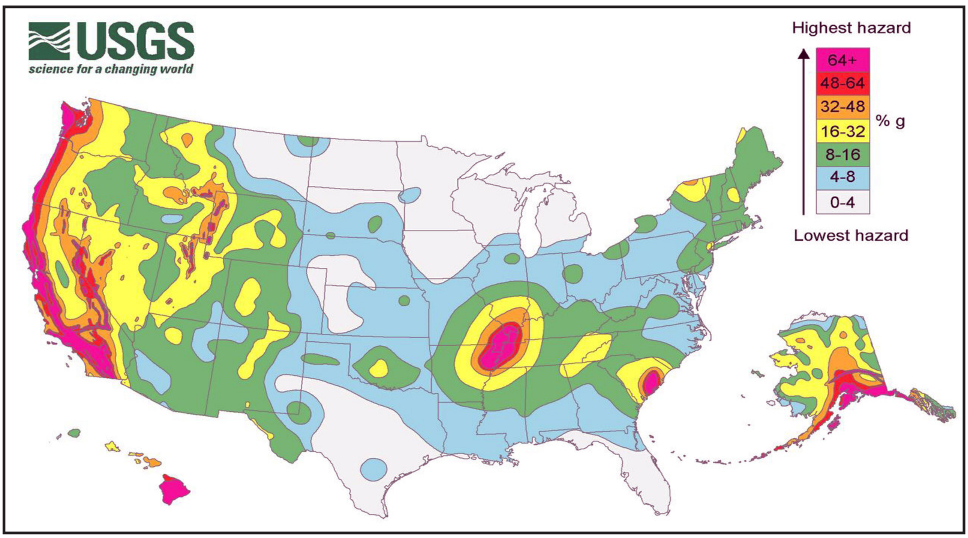

Figure 5-2. Earthquake hazards in the U.S.

One problem with earthquake insurance is that earthquakes cause a wide variety of damage. Destruction of utilities lets fires destroy large areas. Some earthquakes cause landslides and other mass movements.

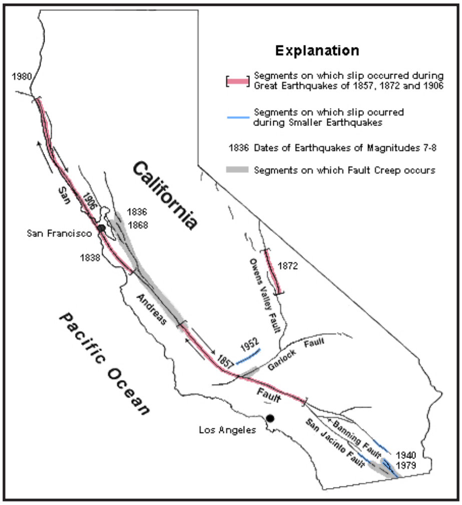

Figure 5-3A (left). San Andreas fault movement, California, USGS.
Figure 5-3B (right). San Andreas fault, California, USGS.

Box 5—1. Building cheaply at Berkeley

The Hayward Fault runs through the campus of the University of California at Berkeley (UCB). The fault is an offshoot of the San Andreas, but it has a different type of movement. The Hayward moves by slow creep instead of rapid jerks that result in earthquakes.

When the leader of UCB realized that "their" fault was relatively harmless, they looked for ways to use it. The fault runs along the western edge of a low range of hills, and the rock in the fault zone is easy to dig because it the rock is already crushed by fault movement.

What an opportunity!

The fault zone could be easily flattened. Seats could be built on the side of the hill. It would only be necessary to build seats opposite the hill in order to have a complete stadium. When UCB finished the project, they called the structure Memorial Stadium.

It is where Berkeley's Golden Bears play home football games.

Mass Movements

Mass movements include many types of gravity-induced downhill movements. We discuss them from the most slow to the most rapid.

The slowest form of mass movement is soil creep (Figure 5-4). This continuous, downhill movement of the soil is shown by bending of the trees. The trees continue to grow straight up as their bottom parts are rotated by soil creep. The wood of these palm trees in Antigua is not strong enough for construction, but rotated pine and hardwood trees have been used for prows of wooden ships.

Figure 5-4. Soil creep in Antigua.

Slumps (Figure 5-5) range from very small, like this one on a stream in Ethiopia (Figure 5-6), to this rotated block in Cafajate, Argentina (Figure 5-7).

Figure 5-5. Slump along road, USGS.

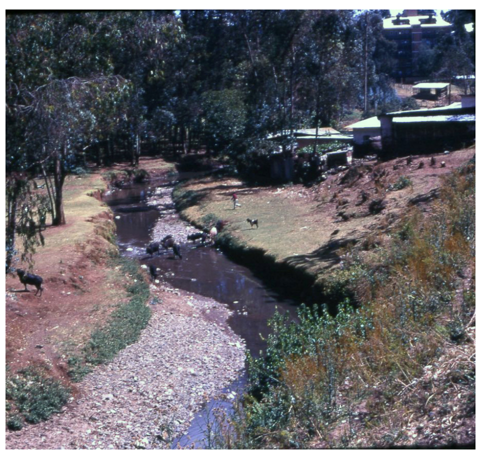

Figure 5-6. Slump along stream in Ethiopia.

Rapid mass movements range from landslides, like this area in the San Juan Mountains (Figure 5-8), to rock falls, as shown on this cliff in Colorado (Figure 5-9). The danger and potential danger from landslides is shown by this false-color photo by the USGS (Figure 5-10; Box 5-2).

Figure 5-7 (top left). Slumping creates rotated block near Cafajate, Argentina.
Figure 5-8 (top right). Landslide in San Juan Mountains, Colorado.
Figure 5-9 (middle). Rockfalls from cliff in Colorado.
Figure 5-10 (bottom). Infrared photo of La Conchita, California, USGS.

Box 5-2. La Conchita

The unincorporated community of La Conchita is squeezed between the Pacific Ocean and steep bluffs. The bluffs, particularly when wet, have a history of sliding into the community (Figure 5-10). The USGS has been monitoring the situation and developed the following statement:

Historical accounts and geologic evidence show that landsliding of a variety of types and scales has been occurring at and near La Conchita for many thousands of years, and on a relatively frequent basis, up until the present. There is no reason to believe this pattern of landsliding will stop.

Even in the absence of additional significant rainfall this year (2005), the remainder of the 1995 landslide could still remobilize, most likely as a deep slump—earth flow similar to that in 1995. This mode of movement would most likely be relatively slow (compared to 2005), but still could pose serious hazards to property and, perhaps, life.

If significant additional rainfall occurs, either this year or in future years, several landslide scenarios are possible: (a) deep movement of the 1995 deposit, as described above, (b) mobilization of the 1995 (and possibly the 2005) deposit into a rapid debris flow such as occurred on January 10, 2005, (c) triggering of subsidiary landslides from parts of the 1995 and 2005 deposits or scarps, (d) triggering of slumps and (or) earth flows on adjacent hillsides, and (e) triggering of rapid debris flows from various nearby slopes, particularly in ravines.

The landslide scenarios sketched above potentially could impact any part of the La Conchita community. Future landslide activity could move into the same areas that recently have been damaged or could mobilize in other directions that could damage any or all of the developed area.

River floods

Rivers flood when they receive too much rainfall or are overwhelmed by snow melt in the spring. Rivers in flood move larger amounts of material and larger fragments than rivers not in flood, and some of this material is dumped when floods subside; examples of this dumping are shown by this large river in Alberta (Figure 5-11) and this small stream near Windhoek, Namibia (Figure 5-12).

Figure 5-11. Large river in northern Alberta, Canada, after a flood.

Figure 5-12. Stream near Windhoek, Namibia, after flood.

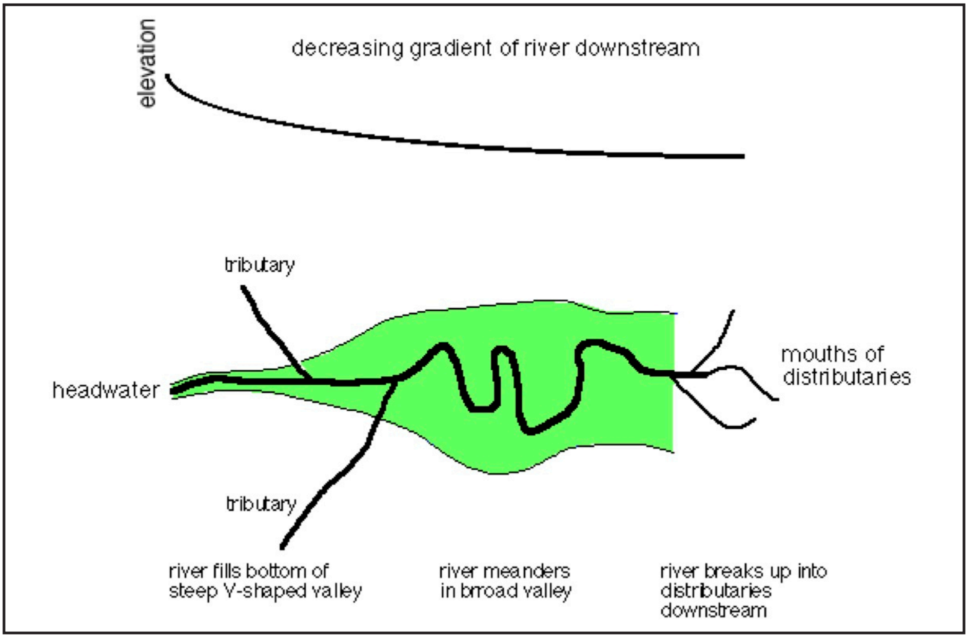

Figure 5-13. Diagram showing changes in gradient and configuration of rivers.

Rivers change character from their headwaters to their mouths (Figure 5-13). Rivers and all their tributaries elongate by eating headward, like this headwater at El Moro (Figure 5-14). As their gradient decreases downstream, they begin to swing horizontally (meander) as well as cutting vertically.

Figure 5-14. Headward erosion at El Moro, New Mexico.

The following series of photos shows typical changes in rivers downstream:

- King's Canyon, California (Figure 5-15). River is cutting valley downward and has not reached stage of valley widening.
- Stream flowing over rapids in Japan (Figure 5-16). The rocks are too hard to permit lateral cutting and valley widening.
- North Fork of American River, California (Figure 5-17), River is meandering and cutting laterally, but eroding mostly downward.
- Nile River, Egypt (Figure 5-18). Mostly lateral cutting widens valley. Flood plain is entire valley.
- River in western Colorado (Figure 5-19) that has widened valley so that entire valley is flood plain. Flood plain is occupied only by cattle, which can be moved during flooding, and not by immovable structures.
- Mouth of river at Lake Pukaki, New Zealand (Figure 5-20). The river is constructing a delta with the fine sediment carried by the river.

The U.S. federal government operates the Corps of Engineers (Box 5-3) and the National Flood Insurance Program (NFIP). The NFIP is insurance against rising water as opposed to falling water (e.g. rain), which is covered by ordinary private insurance policies. Although the government requires private companies to sell the policies, the government sets the premiums and assumes the risk. Premiums are set partly by a Flood Insurance Rate Map (FIRM).

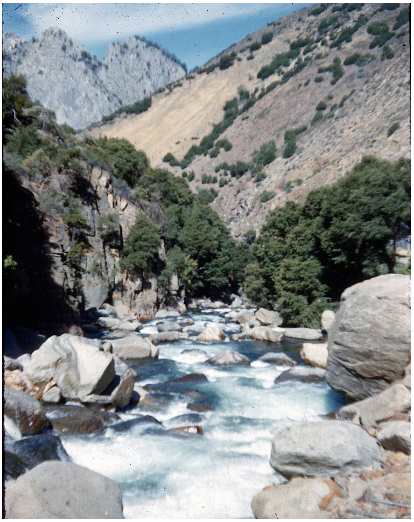

Figure 5-15 (top left). King's Canyon, CA.
Figure 5-16 (top right). Rapids, Japan.
Figure 5-17 (upper middle right). North Fork of American River, CA.

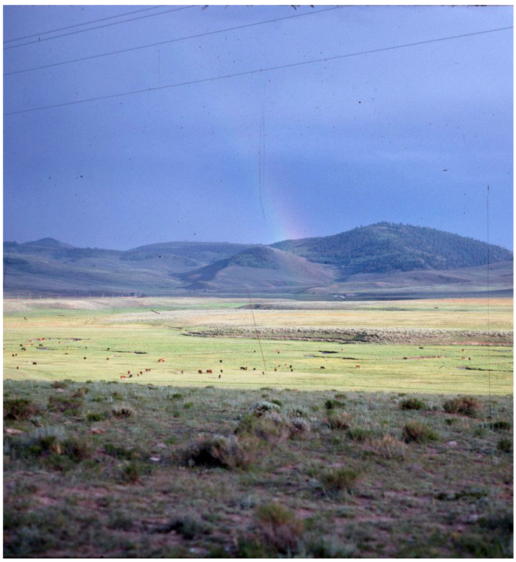

Figure 5-18 (middle left). Nile River, Egypt.
Figure 5-19 (lower middle right). River in western Colorado.
Figure 5-20 (bottom left). River emptying into Lake Pukaki, New Zealand.

Box 5-3. Worry and concrete in Louisiana

(All of the following text in italics is quoted from the U.S. Corps of Engineers.)

There has been tremendous economic development along the present main channel, which includes the cities of New Orleans and Baton Rouge as well as industrial plants elsewhere dependent upon the Mississippi for fresh water and deep water transportation. Three million people are depending upon the present channel of the Mississippi River.

The problem is that the Mississippi is on the verge of running down the Atchafalaya.

That is not just a worry. For some people it's a panic.

The Atchafalaya River has already captured the Red River, which flows from the west and used to be a tributary of the Mississippi. Already 30 percent of the flow of the Mississippi goes into a channel called the Old River and thence into the Atchafalaya River. The configuration is roughly in the form of an H in which the Atchafalaya-Red Rivers form the left leg and the Mississippi the other with the Old River being the cross branch.

The Old River Control Project of the Corp of Engineers is working to prevent the capture of 100 percent of the Mississippi by the Atchafalaya and the pouring of a lot of concrete. *But the Corps of Engineers doesn't want to cut off all flow through the Old River because agricultural and marine development* not to mention alligators *along the Atchafalaya River would be hurt. The Corps is committed to maintaining the 30 percent diversion that now exists.*

Much of the present problem exists because of the past efforts of the Corps of Engineers. Until the nineteenth century, about thirty miles of the channel of the Atchafalaya was blocked by a prehistoric log jam. The Corps and others cleared away this plug of timber. The Red River was also cleared. The Red River had been a direct tributary of the Mississippi for two millennia, but due to the clearing of the Atchafalaya it was captured by the Atchafalaya in the 1940s.

The flood insurance program has been used to reduce flood risks. For example, property owners have been encouraged to “harden” or elevate foundations. Rebuilding of property destroyed by a flood is not always permitted.

Administrators of the program have been lenient toward property owners who developed property before risks were understood and before the federal insurance program went into effect. That leniency mostly ended in 2012, when the government put the program on a more business-like basis. That effort was made via the Biggert-Waters bill, which is described as follows by FEMA (the Federal Emergency Management Agency):

In July 2012, the U.S. Congress passed the Biggert-Waters Flood Insurance Reform Act of 2012 (BW-12) which calls on the Federal Emergency Management Agency (FEMA), and other agencies, to make a number of changes to the way the National Flood Insurance Program (NFIP) is run. Some of these changes already have occurred, and others will be implemented in the coming months. Key provisions of the legislation will require the NFIP to raise rates to reflect true flood risk, make the program more financially stable, and change how Flood Insurance Rate Map (FIRM) updates impact policyholders. The changes will mean premium rate increases for some—but not all—policyholders over time. Homeowners and business owners are encouraged to learn their flood risk and talk to their insurance agent to determine if their policy will be affected by BW-12.

Coastlines

Coastlines undergo both erosion and deposition. Most of the U.S. West Coast is erosional, like this scene in northwestern California (Figure 5-21), and erosion is common in many areas of the world (Figure 5-22). The East and Gulf Coasts of the U.S. are undergoing construction, like this image from Pensacola, Florida (Figure 5-23). An explanation of the features in Figure 5-21 is shown by

Figure 5-21. Coast of northwestern CA.

Figure 5-24. Constructional beaches can also be eroded during storms (Figure 5-25).

Figure 5-22 (left). Erosional coastline in NZ.
Figure 5-23 (right). Coastline at Pensacola, FL.

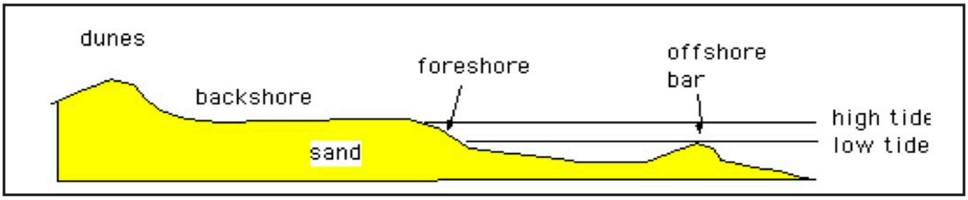

Figure 5-24 (top). Diagram of constructional coastline.
Figure 5-25 (bottom). Erosion of sand at Cape Hatteras.

Environmental issues really do not arise along erosional coasts. Coasts dominated by erosion are obviously places where people should not build structures. Unfortunately, views from sea cliffs are commonly spectacular, and people take advantage of the view to build houses on the cliffs. Private insurance companies will not insure these houses, and governments should leave the risks solely with the owners.

On constructional coasts, structures are built in order to provide views and easy beach access. Providing views and access puts some houses and other structures on top of dune ridges or even on the seaward side of dunes. Some of these structures are elevated in an effort to prevent flood damage from coastal storms. Some people and communities attempt to stop beach erosion by importing sand from elsewhere on the coastline. Structures built landward of dunes, perhaps on the "soundward" side of barrier islands, are generally safe from damage by ocean storms.

The federal flood insurance program (NFIP) is important along beaches. The NFIP insures most properties in beach communities. This raises the problem of whether water damage to a property during a storm was caused by rain and therefore is covered by ordinary insurance policies or was caused by rising water and must be covered by flood insurance.

Volcanoes

Most people do not realize how much volcanoes have affected our lives. They do so mostly by discharge of lava (Figure 5-26), ash (Figure 5-27), and "glowing clouds" (Figure 5-28). Glowing clouds are mixtures of ash and superheated steam that flow at speeds up to 60 miles per hour; they are so hot that they fuse together when they stop flowing and thus form "welded tuffs." It was glowing clouds from Mt. Vesuvius that destroyed Pompeii and Herculaneum. Explosive blasts, like at Mt. St. Helens in 1980, can also occur.

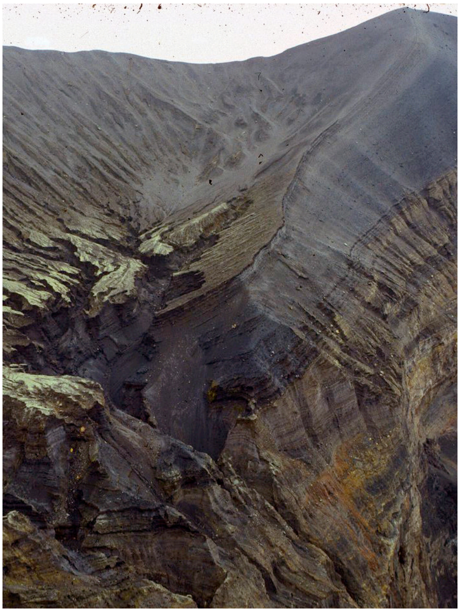

Figure 5-26 (left). Pahoehoe lava in Iceland.
Figure 5-27 (right). Ash in Volcano Irazu, Costa Rica.

Figure 5-28. John Day Formation, Oregon. Resistant layers are glowing cloud deposits.

Two of the largest eruptions that affected human history were in Indonesia. Toba, about 75,000 years ago, was so powerful that it left a lake nearly 70 miles long. Some anthropologists believe that Toba caused differentiation of humans into separate races by isolating people into small interbreeding groups. The 535 AD eruption of Krakatoa that separated the islands of Sumatra and Java brought 'such an ash cover to Europe that cold weather caused widespread famine.' Smaller eruptions were also noticed in Europe (Box 5-4).

Box 5-4. Taupo

Romans noticed that volcanic ash darkened the sky in 188 AD. They lived among volcanoes and knew that local ones were not erupting. So the ash must have come from a large eruption far away.

The Romans didn't know how large and how far. People wouldn't know until New Zealand was settled in the early 19th century. They displaced many Maoris, who had arrived in the 12th century.

When the geology of New Zealand was finally studied, settlers realized that a lake in the middle of North Island occupied the site of a former volcano (Figure 5-29). Evidence of violent eruptions was confirmed by the sizes of some of the debris from the volcano (Figure 5-30).

Dating proved to be difficult. Taupo had erupted several times, but the largest was in 188 AD.

It seems that the 6-mile-wide lake had been created by the volcano's total destruction.

Remember, however, that this blast was small compared to Krakatoa in 535 AD and probably supervolcanoes such as Toba and Yellowstone.

Figure 5-29. Lake Taupo, 6 miles across.

Figure 5-30. Debris from Taupo eruptions.

Only one U.S. eruption in historic time affected the U.S.: Crater Lake Oregon (Figure 5-31) was formed by the eruption of Mt. Mazama 7,700 years ago. The eruption was witnessed by some of the native tribes, and they regarded Crater Lake as a sacred place.

Figure 5-31. Crater Lake, Oregon.

Yellowstone is a supervolcano that has been in continuous eruption for 17 million years (Figure 5-32 and 5-33). Its present record of geysers shows that the area is still active. A similar, but less studied, supervolcano may occur near Mammoth Lakes, California.

Figure 5-32. Yellowstone falls.

Figure 5-33. Geysers at Yellowstone.

Responsibility

Federal and state governments are gradually reducing the amount of risk that they assume for natutal disasters. They investigate issue warnings and, in some cases, predictions. They do not, however, subsudize insurance. Particularly with regard to the NFIP, this lack of subsidy is a departure from previous atttiudes.

The situation in the U.S. is now very clear. People and organizations are on their own. They must understand their risks and either assume the risk themselves or be prepared to pay high insurance rates (if insurance is even available).

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TOPICS FOR DISCUSSION

- Should we control rivers so that they do not overflow floodplains?
- Should we control coastlines so that structures on them are not harmed by storms?
- Should federal and state governments take more responsibility for construction in areas of high risk?

CHAPTER 6
POLLUTION

This chapter considers pollution in its broadest sense: the alteration of the environment so that it is harmful to human civilization. The two major topics are “the myth of primitivism” and “be sure the cure is better than the problem.”

The myth of primitivism

An enduring myth is that people who live primitively are living in harmony with the earth. They are presumed to eat only what they need; they harvest fruit, vegetables, fish, and animals at rates below the natural rates of replacement. They also use energy sources, mostly for fires, at rates less than the replacement rates for the growth of trees or other sources. Primitive living also implies that their waste products do not pollute the environment.

Does our limited knowledge of the lives of primitive people support this concept of harmony? We answer this question with several examples. The first is the village of Skara Brae (Figure 6-1) on the western side of Mainland, Orkney Islands, Scotland. It was a Neolithic village occupied between about 3100 and 2500 B.C.

Figure 6-1. Building at Skara Brae.

The inhabitants of Skara Brae came close to living in harmony with the land in some respects. They apparently lived on vegetables they grew and sheep they raised. Because the Orkneys produce few trees, the people saved driftwood for important purposes, such as roof beams, and they burned kelp for cooking and warmth. The amount of pollution was high, however. Houses were surrounded by “middens” of waste products. The middens were apparently deliberately placed in order to insulate the leaky stone houses against the weather. Also, the absence of any running water meant that human waste products had to be thrown on the land outside the houses.

North American Indians/Native Americans were more numerous than Neolithic people who lived in the Orkneys and demonstrate larger problems. Box 1-6 describes the use of fire and excess killing of animals by Indians in the Carolinas in the early 1600's. This lifestyle continued during European colonization, and the Indians (Figure 6-2) left a huge pile of partly completed and broken lithic fragments at Morrow Mountain, North Carolina (Figure 6-3).

Figure 6-2. Morrow Mountain site of Indian activity.

Figure 6-3. Morrow Mountain, North Carolina. Mountain is surrounded by lithic debris.

Depredations were greater in the midcontinent after the Indians established a lifestyle based on hunting bison. Much of the area was burned over in order to improve grazing. Bison were frequently killed by stampeding herds over cliffs. Some of the animals were used for food, but many were wasted.

In similar fashion, Australian aborigines modified an entire continent (Chapter 1). They used fire to remove the canopy of trees that prevented light from reaching the forest floor and left a flora dominated by fire-resistant trees (Figure 1–14).

Primitive people also used fire on a more local scale. People who did not have access to fertilizer used swiddening to increase agricultural productivity (Chapter 1). This destroys much of the nitrogen in the soil and greatly reduces the variety of crops that can be grown.

With all of this evidence of primitive people using fire to modify their environments massively, how did the myth of primitivism gain credence? Apparently it arose from mistakenly identifying primitive living with life in areas of very low population density. Where populations are small, people can live as hunter–gatherers. They can obtain energy by burning trees that have already died. They make clothes by skinning animals that they kill for food. Their waste products are vanishingly small in comparison to the land that they occupy.

Compare the lifestyle of modern people with the lives of primitive people. One very noticeable difference is our lack of dependence on fire with its resulting environmental consequences. We also use running water to dispose of sewage. Better methods of transportation allow us to concentrate waste in a few places rather than strewing it around the landscape.

Another difference between primitive societies and our present one is the concept of food security. Primitive societies are perpetually either short of food or in danger of becoming so. Our modern society produces more than enough food for everyone in the world. This does not mean that no one is hungry in modern society. Food is a weapon, both in war and, more commonly, in economics. Some people simply cannot afford to buy food for themselves or for their families. Whether it is right for human society to permit hunger in the modern world is a question that we have to deal with.

Thera and the end of Minoan civilization

The explosion of Thera and the resulting tsunamis in the eastern Mediterranean put an end to the Minoans. We finish our comparison of modern and primitive societies by contrasting Indonesian and Minoan civilizations.

The final phase of the eruption of Thera (Box 6-1) caused evacuation of a Minoan town near the modern village of Akrotiri on the island of Santorini (Figure 6-4). We don’t know the name of the town because the Minoans wrote in a roughly Greek script known as “linear B,” which has never been translated.

The exact date of final eruption is controversial. Collapse of the Thera caldera and generation of tsunamis throughout the eastern

Mediterranean probably occurred slightly before 1500 B.C.

Box 6–1. Thera

Thera was once an island with a diameter of about 10 miles. It was also an active volcano. Violent eruptions apparently occurred several times during the few hundred thousand years before the most recent eruption at about 1500 B.C.

The most recent eruption was preceded by the spewing of a few inches of silicic ash over Santorini; whether the ash covered the rest of Thera is unknown. Anyway, the ash at the town near Akrotiri gave residents warning of impending destruction, and the town had been evacuated before cataclysmic eruption (Figure 6–4).

As the eruption continued, 7 meters of ash and tephra were deposited. This phase gradually gave way to glowing cloud eruptions. In the last phase of eruption, the volcano had apparently warmed up and blew 10 cubic miles of rock into the atmosphere. This loss of material caused the center of the island to collapse and form the present ocean-filled basin (Figure 6–5).

Seawater rushing in to fill the newly created caldera caused at least one tsunami to radiate from Thera. Tsunamis and earthquakes originating on Thera affected Minoan establishments on the north coast of Crete, approximately 100 miles away.

The tsunamis destroyed or seriously weakened major Minoan settlements on Crete. Once these strongholds were weakened, Mycenaeans (current Greeks) and other people conquered the Minoans and terminated their civilization. It was a civilization that produced ceramic art and promoted sports for both men and women. There was no indication before the eruption that the society was dying.

Contrast this destruction with the effect of an earthquake and enormous tsunami on Sumatra in 2004. At this time Indonesia had been an independent country for almost 60 years, having declared independence from the Netherlands at the end of Japanese occupation when Japan surrendered to the Allies.

So there is a difference. One tsunami finished the Minoans. One tsunami did not destroy the Indonesians.

Figure 6-4 (top). Minoan town near Akrotiri. Photo by F Eveleens taken in1991 inside shed erected over archeological site. Released for public use under Creative Commons Attribution-Share Alike 3.0 Unported license.

Figure 6-5 (middle right). Landsat image by NASA. Santorini is the large island to the right. Thera caldera is between the two large islands.

Figure 6-6. Santorini seen from the water-filled caldera.

Be sure the cure is better than the problem

Some people always want to do something. Now. This section surveys four examples of environmental significance that raise the question of whether the actions taken were beneficial or harmful. They are: storage of New York City's waste at Fresh Kills, Staten Island; erection of tall smokestacks to reduce SO_2 pollution from burning coal; increasing fertilizer to promote crop growth; and using nuclear power instead of coal to reduce air pollution.

Fresh Kills, Staten Island

The city of New York generates an enormous amount of trash. It seemed logical to store it in Staten Island, which is a borough of the city. In Staten Island, the logical place was Fresh Kills, a swamp. Therefore, in 1947 the city of New York began dumping several hundred tons of garbage per day in Fresh Kills. The pile became high enough to be a hazard to planes landing and taking off from nearby Newark Airport. It became the highest point on the east coast. In 2001, arrangements were made to convert Fresh Kills to a public park and ship compacted trash to a private storage facility in South Carolina.

Tall smokestacks

Erection of tall smokestacks on coal-burning plants in the eastern Midwest was a way of dispersing SO_2. This dispersal took sulfate irritants away from people who lived near the plants, but it left the sulfur in the atmosphere to be carried eastward by prevailing winds (discussion in Chapter 3). Unfortunately, SO_2 reacts with water vapor and oxygen in the atmosphere to form sulfuric acid. Consequently, rain falling in the eastern U.S. carried sulfuric acid. Now some of the lakes in the area are so acidic that they cannot support living organisms.

More fertilizer for crops

One way to increase crop yield is to give them more fertilizer. The fertilizer contains nitrogen and phosphates, both of which can be mobilized into water. This source increases the phosphate from detergents and the nitrogen and phosphate mobilized from manure and from inadequately treated human sewage. The problem is that nitrogen and phosphate not only stimulate growth of agricultural crops, but also the growth of algae and other single-celled organisms that can cause eutrophication in marine and fresh water.

The problem of eutrophication in estuaries has been studied by NOAA, which concluded: When considered together, the 84 estuaries with moderate to high conditions represent 65% of the estuarine surface area studied. The remaining 38 estuaries exhibited low levels of eutrophic conditions, meaning that symptoms were not observed at problem levels or that problem conditions occurred infrequently or only under specific and unusual circumstances..

The relationship between fertilizer and eutrophication leads to numerous confrontations between farmers, who want to increase crop yield, and fishermen, whose fish cannot live in eutrophic water.

Replacing coal with nuclear power

Nuclear reactors do not generate greenhouse gases. Should we therefore replace all coal-fired generators with nuclear plants? Whoa! Consider both real and imaginary problems with nuclear power:

First is exposure of people to radiation. This is generally measured in roentgens (R), which is defined as 2.58 x 10^{-4} Curies per kilogram (rem is “roentgen equivalent man,” which modifies R according to the tissue radiated). Exposure to radiation is a real problem. Normal background gives people about 200 milliroentgens (mR) per year. Consequences of greater exposure expand rapidly. For example, people die if exposed to 500 R in 5 hours (think Hiroshima and Nagasaki).

Disposal of the nuclear waste Is largely an imaginary problem. People ignore the discovery that elements did not migrate even from the un-shielded reactors at Oklo (Box 6–2). They feel safe only if long-lived isotopes such as ^{239}Pu are isolated until they are innocuous.

Nuclear reactors produce various isotopes of Pu (element 94). ^{239}Pu is produced from ^{238}U by absorption of one neutron and loss of two beta particles from short-lived Np (element 93) intermediates. The ^{239}Pu then decays by loss of an alpha particle to ^{235}U.

The half-life of ^{239}Pu is 24,000 years. It is assumed to be innocuous after storage for 10 half-lives (2^{-10} is approximately 0.1%). For ^{239}Pu, this means storage for about one quarter million years.

Box 6–2. Oklo, Gabon

This can't be right. There must be a mistake somewhere. That is what people studying isotopes from the uranium mines near Oklo originally thought. But the measurements were right. The uranium in the veins of pitchblende had gone critical and formed a nuclear reactor.

Because the half-life of ^{235}U is shorter than the half-life of ^{238}U, the percentage of ^{235}U has deceased since the earth formed. It had reached about 3% of total uranium 1,800 million years ago, the age of the uranium veins at Oklo.

But investigators found uranium with as little as 0.44% ^{235}U. It was the reduction that could only be caused in a nuclear reactor. Furthermore, 3% ^{235}U is the minimum ^{235}U concentration for going critical in a reactor moderated by ordinary water. Moderation (neutron absorption) by heavy water would permit criticality at slightly lower percentages of ^{235}U, but the only moderator at Oklo was ordinary ground water.

More evidence of a nuclear reactor came from the study of other isotopes. For example, nuclear fission of ^{235}U created so much ^{143}Nd that the veins contained only 6% ^{142}Nd instead of the 27% in normal earth materials.

The existence of natural reactors nearly 2 billion years old gives scientists an opportunity to study the possible movement of reactor products. These products include elements that would be considered high-level waste from modern reactors. At Oklo, despite the absence of any artificial storage methods, "no widespread migration of the elements occurred" (cited from Brookins, D.G 1982, Environmental Geology, v.4, p. 201–208).

Proponents of nuclear power have never been able to convince opponents that reactors are safe and that their waste products can be stored safely. The quarter-million-year storage time is a major problem.

Whether nuclear power is used more in the future depends on negotiations between its proponents and its opponents.

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TOPICS FOR DISCUSSION

- Should communities store their own garbage?
- Should we replace coal-fired plants with nuclear power?

Personal Opinion

My experience provides two guiding principles concerning the earth's environment. One is a belief in the importance of nuclear power. The second is the necessity of reducing U.S. consumption of the world's resources.

My involvement with nuclear power began with a research program at Rice University, my first faculty position after finishing a Ph.D. at California Institute of Technology. This involvement continued after I left Rice to accept a Kenan Professorship at the University of North Carolina at Chapel Hill.

At North Carolina I did most of my research in India and Africa. This experience in third-world areas showed me the effect of the U.S. having approximately 5% of the world's population and consuming 25% of its resources. Based partly on these observations, I developed my feeling that the U.S. consumes too high a proportion of the world's resources.

Now let me briefly review the major subjects discussed in the book and state my personal opinions about them.

We have a moral obligation to use corn (maize) to feed people. This means that we will no longer feed most of it to cattle, and consequently will eat beef that is simply grass-fed and thus tougher than the beef we have today. Feeding people also means that we will have less high-fructose corn syrup and, consequently, fewer sweetened soft drinks.

Much depends on the choices we make on energy sources. If we continue to use oil and gas, then we must use fracking more extensively. If we plan to replace fossil fuels with nuclear power and other alternatives, then we have to develop these alternatives quickly or reduce our use of energy. Reduction might include elimination of air conditioning in homes.

The only aspect of the earth's climate that we can affect is the concentration of greenhouse gases in the atmosphere. We must reduce emission of greenhouse gases immediately, either by using nuclear power or by other methods. Because other countries, particularly China, are also releasing large amounts of greenhouse gases, we must try to coordinate our efforts with the international community.

Our lack of iron ore and steel alloy resources, makes it necessary for us to develop alternatives to iron and steel. We must also figure out alternative materials for all resources that we don't have domestically.

We must continue and expand our knowledge of natural disasters. Hopefully this knowledge will increase our ability to predict disasters. Despite this increase in knowledge, however, we must not encourage people to live in areas of high risk.

These comments should make it clear that I am a proponent of science and technology. We are more able to resolve environmental problems if we understand them. A corollary to this belief is that I support expenditure of money on scientific investigation.

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U.S. Government documents

I made good use of material by U.S. Government organizations and therefore freely available. These organizations include:

- USGS: U.S. Geological Survey
- NASA: National Aeronautics and Space Administration
- NOAA: National Oceanic and Atmospheric Administration
- FEMA: Federal Emergency Management Agency
- U.S. Corps of Engineers
- CDIAC: Carbon Dioxide Information Analysis Center
- EIA: U.S. Energy Information Agency
- NPS: U.S. National Park Service

Sources of photographs

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