Geomedicine

In earlier chapters (particularly chapters 16 and 17, which dealt with pollution), we considered some of the adverse health effects of anthropogenic substances and the human activities that have caused a redistribution of some naturally occurring substances. Geomedicine, however, encompasses not only pollution, but also investigation of the broader relationships between the natural geologic environment and the health of or occurrence of disease in the people, animals, and plants living in that environment.

Basic Principles of Geomedicine

Trace Elements

Just as most of the earth's crust is composed of only a few major elements, so, too, are most organisms, though the elements involved are, for the most part, different. More than 99 percent of the human body is made of the six elements oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus (table 20.1). In fact, we are about 60 percent water. Most other elements do occur in the body, as they do in rocks, but only at very low concentrations, as **trace elements**. Trace elements may be defined loosely as those found in concentrations of about 10 to 100 ppm or less. The major constituents of the human body are obviously critical to life and health. However, to a great extent, geomedicine is the study of the effects of the presence or absence of the trace elements, or compounds present in equally minute amounts.

Geomedicine has roots that go back centuries; papers appeared in the nineteenth century noting geographical patterns in distribution of disease. However, many areas of the subject are relatively new—for several related reasons. One is that it was necessary to develop instruments sufficiently sophisticated and sensitive to measure extremely low concentrations of elements before their distribution could be determined or studied. Another reason is that it has historically been easier to recognize the effects of the few major constituents than of any one of the many minor ones in people and in other organisms. To take an agricultural example, farmers realized that nitrogen, phosphorus, and potassium are key nutrients required for plant growth long before it became apparent that the trace element boron is required for the proper growth of beets. The importance of iron in the human diet has been realized since the seventeenth century, but for many of the essential trace elements listed in table 20.2, recognition has come only within the last few decades.

The number of trace elements and their varying effects from organism to organism can make the isolation and identification of the function of any one a slow and complex task. A further complication is that the same element can have quite different effects, depending on the concentration in which it occurs or is consumed. This is a well-recognized phenomenon with many drugs. For instance, small doses of the drug digitalin, found in foxglove plants, can be helpful in treating heart problems, but large doses can be fatal, as any murder-mystery fan who has encountered a foxglove-leaves-in-the-salad plot is aware.

Dose-Response Curves

Such variability in effects of trace elements can be described by a **dose-response curve**, on which the positive or negative effects of a trace element are plotted as a function of dosage. Several hypothetical examples are shown in figure 20.1. In case A, the element in question would have no known beneficial or harmful effects in low concentrations but would be toxic in high concentrations and fatal in very high doses. Lead and mercury might be examples of this kind of trace element. In case B, the element is needed to avoid deficiency, but benefits only increase up to a point, after which no particular benefit or harm is derived from consuming higher levels. An element like calcium might be an example: It is necessary to the proper development of bones and teeth, and it would be hard to "overdose" on this major element in the body. Case C, perhaps the most common among the essential trace elements of table 20.2, is one in which a small amount of the element is necessary for optimum health, but too much can be toxic or even fatal. Copper and molybdenum are examples (figure 20.2). We will look at additional examples in more detail shortly.

As a practical matter, there are limits on the extent to which detailed dose-response curves can be constructed for humans. The limits are related to the difficulties in isolating the effects of individual trace elements (see later in this chapter) and in having representative human populations exposed to the full range of doses of interest. Controlled experiments on plant or animal populations are possible, but there is then the difficulty of trying to extrapolate the results to humans with any confidence. It is also true that different individuals, and persons of different ages, may respond somewhat differently to any chemical, trace elements included, so any dose-response curve must either be specific to a particular population, or it must be only an approximation.

Geology, Trace Elements, and Health

Controls on Elemental Intake

The ultimate source of the body's trace elements is the earth—generally, rocks. The various pathways through which the trace elements find their way into the body are summarized schematically in figure 20.3. The concentrations of trace elements in rocks vary by rock type and location and are a fundamental control on the availability of trace elements to humans (table 20.3).

Trace-element concentrations are modified by a variety of natural processes and deliberate and accidental human activities. Rocks weather into soil, gaining, or more often losing, some of their chemical constituents. Soils may lose some elements by leaching; agricultural chemicals and pollutants may be added. Crops selectively remove from the soil the elements they require for growth; animals intensify this selectivity by consuming only certain parts of plants for food. Methods of processing and storing food further change its composition, and we then exercise preferences in diet, consuming only some of the available range of foods and nutrients. The water we drink contains trace elements leached from rock and soil and may also have been polluted or chemically treated. The air we breathe also is a source of a few trace elements, outgassed from the earth, released during volcanic eruptions, or added through pollution.

Superimposed on geologic processes are what might be called "cultural factors," such as dietary choices and pollution, that affect our elemental intake. Examples exist not only in the present but in the past. Ancient Roman aristocrats used cosmetics containing lead and piped their water through lead pipes. It has been hypothesized that the fall of the Roman Empire can be attributed at least in part to widespread lead poisoning and correspondingly decreased fertility among the upper classes.

Within the last few centuries, the idea that geology might be related to health was initially suggested by geographic correlation. Both Kentucky and Ireland are famed for their horses, and both have abundant limestone bedrock; high levels of bone-strengthening calcium derived from the limestone in the soils, grasses, and water of the two regions might be a key factor in explaining the animals' vigor. The frequency of occurrence of certain diseases has seemed to vary by location, to be more common in some places than others. In a few cases, from the coincidence of distinctive chemical characteristics of rock or soil and the distribution of disease, inferences have been drawn that the two might be related. Further controlled experiments could then be undertaken to test the hypotheses.

Iodine

Iodine is necessary to the proper functioning of the thyroid gland. A lack of iodine leads to thyroid enlargement and the deficiency disease known as goiter. Until the last century, the occurrence of goiter was particularly common in the northern half of the United States, an area known as the "goiter belt." Subsequent analysis revealed that the soils in that area were relatively low in iodine; consequently, the crops grown and the animals grazing on those lands constituted an iodine-deficient diet for people living there. When their diets were supplemented with iodine, the occurrence of goiter decreased.

Iodine is not difficult to incorporate into the diet, once the need is identified. Saltwater fish are naturally high in iodine because they live in the salty oceans in which iodine salts are dissolved. Moreover, for half a century, it has been common practice to "iodize" table salt, adding a little sodium iodide or potassium iodide salt to the sodium chloride. Routine use of iodized salt has virtually eliminated goiter without the need for other special dietary precautions.

There may be a geologic reason for the dearth of iodine in northern U.S. soils, aside from any deficiencies in the bedrocks. The northern part of the country was the portion most affected by continental glaciation during the last Ice Age. When the ice melted, huge volumes of water must have drained through the soils on their way to the sea. Iodine salts are quite soluble; perhaps, then, these northern soils had much of their iodine leached out by the glacial meltwaters. (In the midcontinent region, the lack of iodine may be compounded by distance from the ocean; sea spray puts some iodine into the air, from which it falls on nearby land.)

The regional link between soil composition and goiter was particularly clear because, at the time the connection was observed, most people were eating locally grown food. Nowadays, in this and many other developed countries, food production is concentrated in a few areas, and the bulk of most people's food is not locally grown but is brought in from many places. This will make it more difficult to see links between soil chemistry and health in the future, except in countries or areas where most food is still locally produced.

Because extremely high doses of iodine also cause abnormal thyroid function, iodine is an example of the "type C" trace element in figure 20.1. (Excess iodine intake through normal dietary sources, however, is extremely improbable.)

Fluorine

Water chemistry, like soil chemistry, can influence health. Perhaps the best-documented example of a positive relationship between a trace element in water and improved health is the effect of fluorine in reducing the incidence and severity of dental caries (tooth decay). Teeth are composed of a calcium phosphate mineral—apatite. Incorporation of some fluoride into its crystal structure makes the apatite harder and, therefore, more resistant to decay. This, too, was recognized initially on the basis of regional differences in the occurrence of tooth decay.

Fluorine is present in average continental crust at a concentration of several hundred ppm; its concentration in natural waters is much lower, typically only a few ppm. Even such seemingly low concentrations make a demonstrable difference in tooth-decay statistics. Persons whose drinking water contains fluoride concentrations even as low as 1 ppm show a reduction in tooth-decay incidence. This corresponds to a fluoride intake of 1 milligram per liter of water consumed; a milligram is one thousandth of a gram, and a gram is about the mass of one raisin. Fluoride may also be important in reducing the incidence of osteoporosis, a degenerative loss of bone mass commonly associated with old age. Normal total daily fluoride intake ranges from 0.3 to 5 milligrams. (Up to 3 milligrams may be contributed by food, but this varies widely with diet and with the soil chemistry where crops are grown.)

Fluoride is not an unmixed blessing. Where natural water supplies are unusually high in fluoride, so that two to eight times the normal dose of fluoride is consumed, teeth may become mottled with dark spots. The teeth are still quite decay resistant, however; the spots are only a cosmetic problem. Of more concern is the effect of very high fluoride consumption (twenty to forty times the normal dose), which may trigger abnormal, excess bone development (bone sclerosis) and calcification of ligaments. Fluoride, then, might be characterized by the dose-response curve shown in figure 20.4.

The prospect of reduced tooth decay is the principal motive behind fluoridation of public water supplies where natural fluoride concentrations are low. Because extremely high doses of fluoride might be toxic to humans (fluorine is an ingredient of some rat poisons), there has been some localized opposition to fluoridation programs. However, the concern is a misplaced one, for the difference between a beneficial and toxic dose is enormous. The usual concentration achieved through purposeful fluoridation is 1 ppm (1 milligram per liter). A lethal dose of fluoride would be about 4 grams (4,000 milligrams). To take in that much fluoride through fluoridated drinking water, one would not only have to consume 4,000 liters (about 1,000 gallons) of water, but would have to do so within a day or so, because fluoride is not accumulative in the body like some other elements, such as the heavy metals. Even to consume as much as 20 milligrams per day of fluoride, which might cause bone sclerosis, would require the consumption of 20 liters (5 gallons) of water, every day, for a period of time. That, too, is most improbable.

Zinc

Zinc is one of the heavy-metal elements which, nevertheless, appears to be a critical trace-element nutrient, recognized as such since the 1930s. Zinc-deficiency symptoms can take many forms, including dwarfism, dermatitis (skin disease), loss of taste sensitivity, and delay in the rate at which wounds heal. Optimal zinc consumption should fall in the range of 5 to 40 milligrams per day. At doses above 150 milligrams per day, zinc excess may cause anemia; the very much higher dose of about 6,000 milligrams per day is lethal in humans.

Zinc is present at concentrations of about 70 ppm in average crustal rock, but the concentration varies widely with geology. So far, no regional correlation between geology (such as zinc content of water or soil) and the occurrence of zinc deficiency has been found in the United States. However, there is some concern that deficiencies may become more widespread in the future as certain incidental sources of zinc, particularly galvanized items and water pipes, are phased out of our lives. In the absence of dietary supplements, we are becoming increasingly dependent on plants as sources of necessary zinc, and these do show clear regional variations in zinc content. In general, low-zinc sandy soils and soils rich in calcium carbonate produce more zinc-deficient plants. A single plant species might show a range in zinc content from only a few ppm on a zinc-poor soil to several thousand ppm elsewhere. While regional zinc deficiencies closely correlated with local geology might be avoided by interregional food transport, widespread zinc deficiencies could result if large proportions of some important food plants were grown in low-zinc regions.

Selenium

Selenium is quite a rare metal, for which excess is more often a concern than is deficiency. Its concentration in most rocks and soils is less than one-tenth part per million, and normal selenium intake in humans is 0.006 to 0.2 milligrams per day. Lack of selenium has been shown to cause abnormalities in many plants and animals; selenium deficiency symptoms in humans are not well documented except in the Keshan region of southeastern China, where the most selenium-deficient soils known are found. On the other hand, selenium toxicity (when more than about 5 milligrams per day is consumed) is well recognized, reflected in development of cancers, malformation of nails and hair, depression, nervousness, and other symptoms in humans.

While soil chemistry is a major control on selenium uptake in plants, different species have been shown to vary widely in the degree to which they absorb selenium from the soil. The “locoweed” known in the western United States, actually a group of plant species of the genus *Astragalus*, concentrates selenium strongly. The informal name derives from the selenium poisoning that occurs in livestock that graze on it: The animals develop a disease known as “blind staggers.” Other selenium-concentrating plants are used in prospecting for ores, including uranium ores. Among human food crops, plants that concentrate sulfur—which include cabbage, mustard, and onions—also concentrate the geochemically similar selenium.

Where levels of soluble selenium in the soil are high, most varieties of vegetation grown on that soil will also be high in selenium, whether those varieties particularly concentrate selenium or not. In the early 1930s, one farm in South Dakota, known locally as the Reed farm, had a history of frequent changes of ownership. In time, each new owner usually filed a lawsuit charging misrepresentation against the former owner. Chicken eggs did not hatch or the chicks were malformed; cattle and horses became sick. Eventually, the trouble was traced to selenium-rich crops, especially wheat, grown on the farm. After the problem was identified, the federal government bought up the most seriously affected farms in the region.

Fortunately, the number of places in the world having soils that routinely produce deadly selenium-rich crops is small. Selenium is somewhat concentrated in volcanic rocks and in the soils derived from them (as in Hawaii, for instance) as well as in certain shales rich in sulfide. The desert plume plant of the southwestern United States, in fact, *requires* selenium-rich soil, so its presence is a clue to the possible hazards of the soil chemistry. Selenium is also more readily leached from the pedocal soils common to the western United States. In early 1985, it was discovered that runoff drained from farmland in California’s San Joaquin Valley and dumped in ponds in the Kesterson Wildlife Refuge (figure 20.5) was causing deaths and deformities among the local duck and fish populations. The culprit appears to be selenium in the water, leached from the farm soils.

Interestingly, the problems became acute only as a result of human activities. The area's shale-derived soils were naturally high in selenium (figure 20.6), but in this normally dry area, the selenium was ordinarily relatively immobile (figure 20.7). Only with the extensive flooding of the land for the cultivation of rice were high levels of selenium leached, washed into the ponds of Kesterson, and there concentrated by evaporation, increasing the flux to those surface-water reservoirs, disrupting the established geochemical cycle, and creating a hazard to wildlife. Selenium, like the heavy metals, can be accumulative in the food chain, so selenium toxicity symptoms were noted in birds (at the top of an algae → insects → fish → birds → chain) before toxic selenium concentrations were achieved in the water of Kesterson.

Radon

The problem of radon as a pollutant of indoor air was discussed in chapter 17. A fundamental control on the extent of the hazard is the underlying regional geology, and especially the concentration of uranium in the rocks (figure 20.8). Rocks that may have relatively high uranium contents include granites, silicic volcanic rocks, phosphate-rich sedimentary rocks, sulfide-rich shales, and metamorphic rocks formed from any of these.

The quantity of a radioactive material may be expressed in units of *curies*, where one curie is the activity (number of radioactive decay events per unit of time) of one gram of pure radium. (The unit is named for Marie Curie, who discovered radium.) One curie = 37,000,000,000 disintegrations (decays) per second. This would be an extremely intense and hazardous level of radiation; environmental radiation levels are more often measured in picocuries (pCi), where a picocurie is one trillionth of a curie, or .037 disintegrations per second, or about 133 radioactive decay events per hour. Figure 20.9 illustrates the range of radon activities in ground water, air in soil, and indoor and outdoor air.

The potentially carcinogenic effects of radon exposure were recognized earlier in populations exposed to high radiation levels (e.g., uranium miners). As with any radiation exposure, it is difficult to assess precisely the risk represented by low doses. Given the concentrating effects of well-sealed houses relative to outdoor air, it is at least clear that the risk increases in such structures, and clearly the higher the natural radiation levels resulting from the particular geologic setting, the higher the risk associated with concentrating that radon.

Cases in Which Connections Are Less Clear

In the previous examples, a clear relationship could be established between geochemistry and health because a specific chemical substance could be identified with particular deficiency or disease symptoms. On the frontiers of medical geology, considerable efforts are being made to establish the causative links more firmly where they are presently unknown.

Radioactivity and Tobacco

Cigarette smoking has been associated with the increased occurrence of lung cancer. While certain chemical components in tobacco have certainly been shown to be damaging, it has also been suggested that agents of geologic origin may indirectly be partly responsible also. The phosphate fertilizers spread on cropland tend to be somewhat enriched in uranium, as a consequence of the natural geochemistry of uranium and phosphate. As noted in chapter 17, one product of uranium decay is radon gas. It is hypothesized that this naturally occurring radon gas rises from the soil to be adsorbed onto tobacco leaves, where it decays, in turn, to solid radioactive products, including isotopes of lead and bismuth (figure 20.10). These radioactive particles would be inhaled with the smoke and could lodge in the lungs, where the radiation from their decay could cause cancer. There is a good deal of speculation in this scenario, but it is plausible and worth testing further.

Regional Variations in Heart Disease

In a number of instances, geographic variations in occurrences of particular symptoms are known, but there is either no known parallel pattern in the geology or no clear connection recognized between the known geologic variables and the particular health problem. For example, it has been known for two decades that the hardness of public water supplies shows regional variations, rooted in geology, that are broadly similar to the variations in death rate from certain types of heart disease (figure 20.11). In the central United States, where limestone-rich aquifer systems contribute to relatively hard water, coronary heart disease death rates are generally lower. Along the Atlantic coast, the water is much softer, and the heart-disease death rates are relatively high. Why?

So far, no single answer has emerged. Is there something beneficial in hard water that protects against heart disease in some way not yet recognized? Soft water is usually more acidic than hard water, and acids more readily leach metals from pipes—does that result in consumption of one or more metals that somehow cause heart disease? Many people living in hard-water areas use water softeners, which add salt to the water, and sodium has been implicated in cardiovascular disease; but not everyone in hard-water areas drinks softened water. Does the water chemistry, in fact, have any causative link with heart disease at all? Not necessarily; the apparent connection might be pure geographic coincidence. Perhaps the stress of living in East Coast cities rather than in more rural areas of the Midwest is a causative factor. Perhaps no one has even proposed the right answer yet. Still, the similar geographic patterns in heart disease and water hardness are there, and they are intriguing. Also, the same kind of geographic correlation between these two particular parameters has been observed in twenty-seven studies in eight countries, which strengthens the impression that some genuine cause-and-effect relationship between water chemistry and the disease exists.

Cardiovascular Disease in Georgia

Another puzzling geographic pattern is the regional variation in cardiovascular-disease death rates in Georgia, which corresponds to variation in the underlying geology (figure 20.12). The counties with the lowest death rates are all in the Appalachian highlands in the northern part of the state. The counties with the highest death rates lie wholly or partially within the Atlantic coastal plain to the south. This observation inspired exhaustive geochemical investigations to try to find a geologic cause for the pattern.

Soils, plants, trees, and food crops were analyzed for thirty different elements and the analyses compared between regions. In general, the soils of the coastal plain are more weathered and more extensively leached. The highland soils are significantly higher in aluminum, barium, calcium, chromium, copper, iron, potassium, magnesium, manganese, niobium, phosphorus, titanium, and vanadium, and somewhat lower in zirconium. Several of these elements (chromium, copper, manganese, and vanadium) are believed to have some beneficial effect on the cardiovascular system. However, no simple relationship was found between soil chemistry and the chemistry of vegetables grown on that soil, and it is, after all, the vegetables that are consumed, not the soil. The sources of drinking water in the region were so numerous and varied, including both public and individual supplies, surface and subsurface sources, that systematic sampling and analysis could not be undertaken. Yet the water might be a significant factor. More sampling and further studies to confirm the influence of some of these trace elements on cardiovascular function are needed before any straightforward explanation of the death-rate pattern in terms of geology can be shown.

This study illustrates one of the special problems faced by medical geologists as opposed to laboratory scientists. In the lab, it is possible to control experiments, to vary one parameter, such as the concentration of one chemical element, at a time. In nature, dozens of chemical characteristics are likely to be varying at once from place to place. It becomes correspondingly far more difficult to pick out the influence of any one. The situation is further complicated by interactions between trace elements, as will be shown shortly.

Other Intriguing Patterns

Other diseases show strong geographic variations that might be tied to geology. In Iran, the rate of occurrence of cancer of the esophagus shows a regional pattern that strikingly mimics the distribution of soil types (figure 20.13). Whether the soil chemistry has, in fact, any direct influence on the incidence of the cancer is not known. Elsewhere, possible geochemical causes have been proposed to explain regional variations in the frequency of occurrence of other forms of cancer and of gout. The incidence of stomach cancer in Wales, for example, seems to be correlated with the amount of organic matter in the soils. Whether this is a consequence of the tendency of organic matter to concentrate some potentially toxic metals or of some other factor is not presently known.

There also are correlations with a less obvious geochemical basis. A recent study of death rates from one type of heart disease in Europe suggested a correlation with the age of the rocks in the region (table 20.4). A given age group may comprise a wide variety of rock types, and the same rock type may be found in regions of several ages. Thus, geology cannot be related in any simple way to the pattern of death rates. Certainly, why the *age* of a rock, by itself, should make any particular difference to the health of those living above it is not at all apparent. In this case, it may be easy, intuitively, to dismiss geology—or at least rock age—as a probable causative factor. Where spatial correlations with chemical factors are observed, however, it is more difficult to establish or refute a connection.

There are also situations in which expected regional correlations are absent. There are clear regional variations in radon levels in rocks and soils, and consequently in homes. Yet so far, corresponding consistent regional variations in occurrence of lung cancer have not been clearly documented, perhaps because these variations are masked by other factors causing lung cancer, such as cigarette smoking.

Further Complicating Factors

Cause-and-Effect or Coincidence?

Medical geologists must distinguish those correlations that arise because of cause-and-effect from apparent correlations that do not. A tobacco company pointed out several years ago during an advertising campaign that more people die in bed than anywhere else, but that hardly means that it is dangerous to go to bed. One might observe a much higher percentage of gray-haired listeners at a symphony concert featuring classical music than at a rock concert, but it would surely be scientifically irresponsible to conclude that classical music causes gray hair. Many obviously silly examples could be constructed to prove the point that coincidence in time or space of two things does not at all indicate a cause-and-effect relationship between them. Similarly, the fact that the geology of a particular area may seem to be correlated with a higher or lower incidence of a particular disease does not by itself prove any causal connection between the two.

Trace-Element Interactions

As noted earlier, genuine cause-and-effect relationships may be especially hard to recognize in natural geologic systems, in which numerous mineralogic and geochemical parameters vary simultaneously and in different ways. The picture is further clouded because the effect of a particular element often is modified in the presence of other elements. An example is shown in figure 20.14. The incidence of copper deficiency in cattle in central England appeared strongly correlated with underlying geology, with most cases in or near areas underlain by shales. Yet the shales and the soils derived from them were not markedly poor in copper. They *were* rich in molybdenum, as were many streams in that area, and this was the source of the problem. Apparently, increased intake of molybdenum increased the need for copper in the animals' diets. Animals drinking from less-molybdenum-rich streams might show no signs of copper deficiency even when the levels of copper in their blood were relatively low.

Other known and suspected interactions abound. Plants growing in high-phosphorus soils (including those enriched by fertilizers) are frequently deficient in zinc. Uptake of high levels of zinc by plants may limit the extent to which the plants can absorb cadmium; thus, application of zinc to cadmium-rich soils may be helpful in controlling a potentially harmful accumulation of high cadmium concentrations in food crops. Sulfur may "compete with" selenium during uptake in plants, but experimental results are inconsistent: Applying sulfur-bearing fertilizers to low-selenium soils has depressed the levels of selenium in plants even further, but on the other hand, efforts to prevent accumulation of high selenium levels in plants growing on selenium-rich soils by applying sulfur have not worked well.

In animals, metabolic processes involving magnesium, potassium, and calcium have been shown to be interrelated, and evidence indicates that the same is true in humans. Thus a deficiency in one element may upset the balance of another. Copper is essential to the proper metabolism of iron; molybdenum may also affect iron metabolism. Plant fiber may inhibit the absorption of zinc in the human digestive tract. In plants, phosphorus may inhibit uptake of zinc, causing zinc deficiency in plants (and higher organisms, including humans, consuming the plants); this can be a particular problem because phosphorus is a major ingredient in fertilizer. Zinc and cadmium may compete in humans as well as in plants; hence, increased zinc consumption may afford some protection against cadmium. Selenium may protect against the harmful effects of some mercury compounds (but, of course, selenium in turn is potentially toxic and thus should not be consumed indiscriminately).

The list of established and suspected interactions is extended year by year. Some of the interactions—especially competition among elements—can be anticipated from the elements' positions in the periodic table (figure 20.15). Elements in the same column (sulfur (S) and selenium (Se), column VIa; zinc (Zn) and cadmium (Cd), column IIIB; calcium (Ca) and magnesium (Mg), column IIa) have similar electronic structures and may therefore show similar bonding characteristics. Other apparent interactions between less similar elements (copper and molybdenum, for example) obviously involve more complex chemistry and biochemistry and are not so readily identified or understood. The growing recognition of trace-element interactions is one reason why doctors warn against consuming large doses of mineral supplements containing a few specific elements. Aside from any potential toxic effects of the particular elements consumed, there is concern that chemical imbalances of other elements could be created, with serious health consequences.

Distinguishing Risk from Risk Perception

Costs of asbestos abatement over the last decade or so are estimated to have totaled tens of billions of dollars for commercial buildings alone. Yet much of this expenditure may have addressed a nonexistent or insignificant risk. It is quite true that studies have documented increased incidence of certain cancers and other health problems among miners and other workers with high occupational exposure to some kinds of asbestos. However, it does not follow that all asbestos everywhere is dangerous.

First, there are six different silicate minerals that are called “asbestos,” for the term is used to describe various minerals with a fibrous habit. By far the most common—accounting for an estimated 95 percent of asbestos mined and used in the United States—is *chrysotile*, a hydrous chain silicate (figure 20.16). Yet there is little or no evidence that chrysotile poses a health risk to the general population; indeed, one case study of a school in Ambler, Pennsylvania, where for over a century, schoolchildren have been exposed to a 150,000-ton pile of chrysotile-containing material beside the school, showed not a single documented case of asbestos-caused illness. Even where occupationally exposed workers had somewhat elevated incidence of lung disease, the possible effect of asbestos could not be clearly separated from effects of the workers’ smoking. Some of the rarer asbestos minerals show clearer risk; but asbestos-abatement legislation does not make mineralogical distinctions among asbestos varieties.

Part of the push for asbestos abatement, too, comes from the unverified “one-fiber” theory—the assumption that a single asbestos fiber may cause, for instance, lung cancer, or other asbestos-related disease. But fibrous minerals, like dust, are everywhere: it is estimated that, breathing average outdoor air, a normal human would inhale nearly four thousand asbestos fibers a day! This is not to say that occupational exposures for those who work with asbestos materials should not be regulated in the interest of workers’ health. The risks to the general public from asbestos, however, would seem to be far lower than commonly perceived, and much of the investment in “abatement” of chrysotile-containing material, in particular, may be far out of proportion to the risks that it actually presents.

Impacts of Human Activities

Human activities are modifying trace-element concentrations in many ways, some of which were already considered in this and the previous two chapters. Soil pollution with metals (lead, zinc, copper, cadmium, arsenic, uranium, and others) is common near smelters and other ore-processing facilities, and the pollution may lead not only to water pollution but also to contamination of plants growing nearby. Soils and plants growing near busy highways frequently showed elevated lead levels due to pollution from car exhaust. Consideration of the possibility of substituting manganese compounds for now-banned lead in gasoline has, in turn, raised concerns about possible manganese poisoning: Nerve and brain damage from excess exposure are known to occur in some miners and other workers exposed to high levels of manganese. Agricultural practices, including modification of the hydrologic cycle (as by irrigation with attendant redistribution of leachable elements) and application of natural or synthetic fertilizers that may add key trace elements, modify geochemical cycles by changing chemical fluxes and residence times. These and other modifications of natural elemental cycles mask the basic geologic factors influencing health and disease, making the medical geologist's task more difficult.

And new environmental health problems continue to emerge. One of the newest is the discovery that certain pesticides can mimic hormones in the bodies of humans and other animals, causing anomalous development of various kinds. Some appear to suppress the immune system, lowering an organism's resistance to disease. Others are believed to cause reproductive problems, or anomalies in the development of embryos. While over 60 percent of pesticide sales are currently in the U.S., Western Europe, and Japan, pesticide use is increasing far more rapidly in developing nations, where mortality rates are already high. Many agencies are now calling for more extensive and detailed studies of the toxicity of these pesticides.

Summary

In a growing number of instances, the geology and geochemistry of the environment have been shown to bear on the chemistry and health of plants, animals, and people. Many of these effects are independent of human activities such as those causing pollution. Often, they are recognized initially through geographic variations in occurrence of a particular disease. The identification of significant natural geochemical or mineralogic factors is complicated because cultural factors are superimposed on natural geologic and biologic systems, by complex interactions between trace elements in which the presence or abundance of one modifies the effect of another, and by the difficulty of isolating the effects of a single chemical substance from the dozens of geochemical parameters that vary simultaneously with local geology. Better understanding of the medical importance of naturally occurring trace elements could lead to the elimination of many instances of regionally chronic excess or deficiency diseases having a geologic basis. The health hazards of synthetic chemicals in the environment are not always well determined. There are currently numerous examples of geographic variations in disease occurrence that may arise from geologic factors but for which the specific cause is speculative or wholly unknown. Conversely, there are cases of overreaction to a perceived geologic health hazard, as with asbestos abatement.

Terms to Remember

dose-response curve
trace elements

Exercises

Questions for Review

2. What are trace elements? Are the trace elements in humans the same as those in rocks? Explain.
2. Draw a hypothetical dose-response curve and explain it.
3. Outline the pathways through which trace elements enter the body, noting both natural processes and human activities that alter the elements' concentrations along the way.
4. Links between regional soil chemistry and health may nowadays be easier to recognize in less-developed countries. Why?

5. An apparent connection between water hardness and the incidence of heart disease is well documented in many countries. Suggest several possible explanations.
6. Does a correlation in time or space between two factors or events indicate a cause-and-effect relationship between them? Explain.
7. The concentration of one trace element may alter the effect of another. Describe an example. How does this complicate geomedicine?

For Further Thought

1. Examine the label of a package of multivitamin-plus-mineral tablets. How many of the essential trace elements of table 20.2 are included? Are any additional elements included for which a need has not yet been clearly established?
2. Investigate the possibility of unusual trace-element concentrations in soils in your area. (The county Extension Service or an agricultural college may have relevant data.) Are any of the anomalies believed to be particularly beneficial or potentially harmful? If so, what (if anything) is being done about them?

Suggested Readings/References

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NetNotes

The U.S. Agency for Toxic Substances and Disease Registry is a good source of fact sheets that respond to frequently asked questions (FAQs) about various health hazards, including geologic ones. Their home page, through which one can also access a new newsletter, Hazardous Substances and Public Health, is at http://atsdr1.atsdr.cdc.gov:8080/HEC/hsphhome.html

The FAQ fact sheets are accessible more directly via http://atsdr1.atsdr.cdc.gov:8080/toxfaq.html

The Citizen Information Page of the U.S. Environmental Protection Agency includes information sheets on potential health hazards such as lead and radon, at http://www.epa.gov/epahome/Citizen.html

EPA's Citizen Guide to Radon is found at http://www.epa.gov/docs/RadonPubs/citguide.txt.html

The U.S Geological Survey offers a variety of information on radon at
http://sedwww.cr.usgs.gov:8080/radon/radonhome.html

A variety of environmental-medicine case studies are accessible via
http://uhs.bsd.uchicago.edu/case.studies/index.html

Canada's Environmental Health directorate, a division of Health Canada, can be reached at
http://www.hwc.ca/dataehd/English/opening.htm

Canada is a major supplier of chrysotile asbestos. The Canadian-based Asbestos Institute is at
http://www.asbestos-institute.ca/

Highlights of a World Resources Institute report, "Pesticides and the Immune System," can be found online at http://www.wri.org/wri/health/pis-high.html

Table 20.1

*Principal Chemical Constituents of the Human Body**

Element	Percentage of body weight
oxygen	61
carbon	23
hydrogen	10
nitrogen	2.6
calcium	1.4
phosphorus	1.1
Total	**99.1**

Source: R.M. Parr, "Trace Elements in Human Milk," *International Atomic Energy Agency Bulletin 25*, 2 (1983): 8.
*All other elements—led by sulfur, potassium, sodium, and chlorine—make up the other 0.9 percent of the body.

Table 20.2

Essential Trace Elements in Humans

Element	Average body concentration (ppm)	Year recognized as necessary	Function	Some effects of deficiency in humans
iron	60	17th century	oxygen transport	anemia
iodine	0.2	1850	component of thyroid hormones	goiter
copper	1	1928	interacts with iron; in some enzymes	anemia, bone changes; possible elevated cholesterol
manganese	0.2	1931	involved in metabolism	not known
zinc	33	1934	involved in metabolism	depressed growth, slow healing
cobalt	0.02	1935	in vitamin B_{12}	seen as B_{12} deficiency
molybdenum	0.1	1953	in some enzymes	not known
selenium		1957	in enzymes; interacts with heavy metals	selenium deficiency heart disease
chromium	0.03	1959	involved with insulin action	insulin resistance; lowered glucose tolerance
tin*	0.2	1970	not known	not known
vanadium*		1971	not known	not known
fluorine	37	1971	important to proper tooth and bone growth	increased tooth decay; osteoporosis
silicon	260	1972	calcification; may function in connective tissue	not known
nickel	0.1	1976	interacts with iron absorption	not known
arsenic*	18	1977	not known	not known
cadmium*	0.7	1977	not known	not known

Source: R.M. Parr, "Trace Elements in Human Milk," *International Atomic Energy Agency Bulletin* 25, 2 (1983): 8.

*Need in humans not directly established; inferred from animal experiments

Table 20.3
Variations in Composition Among Common Rock Types*

Element			Average concentration		
	GRANITE	BASALT	SANDSTONE	SHALE	CARBONATE
silicon (%)	32.3	24.0	36.5	27.1	2.4
aluminum (%)	7.7	8.8	3.0	9.7	0.5
iron (%)	2.7	8.6	1.0	4.7	0.4
magnesium (%)	0.6	4.5	0.7	1.5	4.8
calcium (%)	1.6	6.7	3.9	2.2	30.0
sodium (%)	2.8	1.9	0.3	1.0	0.04
potassium (%)	3.3	0.8	1.1	2.7	0.3
titanium (ppm)	2,300	9,000	4,600	1,500	400
phosphorus (ppm)	700	1,400	750	170	400
manganese (ppm)	600	2,000	850	10–100	1,100
chromium (ppm)	25	200	100	35	11
copper (ppm)	20	100	50	1–10	4
lead (ppm)	20	8	20	7	9
nickel (ppm)	8	160	80	2	20
cobalt (ppm)	5	45	20	0.3	0.1

Sources: A. Brownlow, Geochemistry, copyright © 1979 Prentice-Hall, Inc., Englewood Cliffs, NJ; K.B. Krauskopf, *Introduction to Geochemistry*, copyright © 1979 McGraw-Hill, Inc., New York, NY; and B. Mason and C.B. Moore, *Principles of Geochemistry*, copyright © 1982 John Wiley & Sons, New York, NY.

*Data are presented for major elements and selected minor elements.

Table 20.4
Apparent Relationship Between Age of Rocks and Heart Disease

Age of surface and underlying rocks	Countries	Mean ischemic heart disease rate, 1967 (per 100,000 population)
Precambrian (over 600 million years)	Sweden, Finland, Denmark, Scotland	314
Early Paleozoic (600–300 million years)	Norway, England, Northern Ireland	291
Late Paleozoic (300–180 million years)	Ireland, Austria, Hungary, France, Germany, Netherlands, Belgium, Czechoslovakia, Poland, Spain, Portugal, Romania	175
Mesozoic or younger (under 180 million years)	Italy, Yugoslavia, Bulgaria, Greece, Switzerland	159

Source: R. Masironi, “World Health Organization Studies in Geochemistry and Health,” *Geochemistry and the Environment*, vol. 2, 132–138, National Research Council, 1977.