

*Understanding
Our Fragile Environment*

*Lessons from
Geochemical Studies*



Public Issues in Earth Science

U.S. Geological Survey Circular 1105

All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts. His instincts prompt him to compete for his place in that community, but his ethics prompt him also to co-operate (perhaps in order that there may be a place to compete for). The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the lands.

Aldo Leopold—*A Sand County Almanac*

Front cover: *Fireweed, the state flower of Alaska, is an early colonizer of lands disturbed both naturally and by human activity. Following the May 18, 1980, eruption of Mount St. Helens, this wildflower was among the first plant species to colonize volcanic ash that was deficient in both organic matter and nutrients.*

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FOREWORD

As part of the special interest series, *Public Issues in Earth Science*, published by the U.S. Geological Survey (USGS), this Circular describes the importance of the earth sciences in the investigation of environmental problems. The report focuses on geochemistry—the study of the amounts, distribution, and cycling of chemical elements in the Earth and atmosphere—and how this science helps to evaluate critical issues that relate to our fragile environment.

The mission of the USGS is to provide geologic, topographic, and hydrologic information that contributes to the wise management of the Nation's natural resources and promotes the health, safety, and well-being of our people. Part of this task includes characterizing the Nation's geochemical environment and understanding the dynamic processes responsible for change in that environment.

One of our greatest assets at the USGS is our long tradition of excellence in unbiased earth-science research. Part of that legacy is our commitment to supply the geochemical information necessary to confront urgent environmental challenges. Geochemistry provides information on the distribution of chemical elements to help us define and understand environmental problems. This information then allows us to provide answers for their resolution and possible remediation.

This Circular presents an overview of geochemistry and its application to various case studies that illustrate the use of geochemistry in examining environmental problems. Some new and exciting areas of environmental geochemistry are discussed, involving rock/water, soil/water, and plant/soil investigations. These investigations focus on many of our natural resources including minerals, soil, water, air, and vegetation and examine environmental concerns—such as acid precipitation, mine drainage, and sources of contamination—from a “systems” or “holistic” approach.

As the primary Federal earth-science agency, the USGS leads in the collection, interpretation, and dissemination of earth-science information. This report helps to define one area in which the USGS is an active participant—the application of geochemistry to environmental concerns.

Dallas L. Peck
Director



USGS scientist sampling water from a uranium-rich spring in a Colorado wetland.

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Introduction to Environmental Geochemistry

Minerals, trace elements, contaminants, and hazards

An understanding of our fragile environment can begin with a recognition of the importance of certain elements, commonly called “minerals substances” (such as iron and zinc), in the lives of humans and animals and in the soils that support plants. This recognition is well deserved because these elements are essential for the life or optimum health of an organism. Some elements such as carbon, hydrogen, oxygen, magnesium, potassium, and phosphorus are required in relatively large amounts by organisms. However, others are required in smaller quantities; these are referred to as *trace elements*. Diseases have been related to the deficiency of about 20 elements in animals and humans and to the deficiency of approximately 13 elements in plants.

At the same time, if these and other elements occur in quantities great enough, toxicity can result. An element, or any substance, that occurs in the environment and contains concentrations above what are considered to be background levels may be considered a *contaminant*. When contaminants occur at levels that are potentially harmful to organisms, they are labeled as *hazards*. Often the quantitative difference between essential amounts and toxic concentrations of these elements is very small. For example, the trace element selenium is required at a level of no less than 0.4 ppm in the diet of cattle but can be toxic at levels greater than approximately 4 ppm.

Elements that are required for survival by animals and plants are termed *essential*,

The biogeochemistry of life—essential elements				
Essential to all animals and plants:	Essential to several classes of animals and plants:	Essential to a wide variety of species in one class:	Essential to one or two species only:	Recent work indicates essentiality, but of unknown function:
Hydrogen (H) Carbon (C) Nitrogen (N) Oxygen (O) Sodium (Na) Magnesium (Mg) Phosphorus (P) Sulfur (S) Chlorine (Cl) Potassium (K) Calcium (Ca) Manganese (Mn) Iron (Fe) Copper (Cu) Zinc (Zn) Selenium (Se)	Silicon (Si) Vanadium (V) Cobalt (Co) Molybdenum (Mo) Iodine (I)	Boron (B) Fluorine (F) Chromium (Cr) Bromine (Br)	Lithium (Li) Aluminum (Al) Nickel (Ni) Strontium (Sr) Barium (Ba)	Rubidium (Rb) Tin (Sn)
Elements in bold type are generally considered to be trace elements.				

The biogeochemical cycle

Chemical elements move through the environment in biogeochemical cycles. There are three major components to this process: (1) an element *source* (where did the element come from?—for example, rocks, soils, waste sites, contaminant spills, to name a few), (2) a *transport* mechanism (how does it move through the environment?), and (3) a place of *deposition* (where, how, and why does it stop moving?).

We call this cycle biogeochemical because, in addition to the role of chemical and physical processes, the cycling of elements strongly depends on its interaction with living organisms—from bacteria to humans.

while those not required are *non-essential*. Trace essential elements such as fluorine, copper, selenium, molybdenum, and others listed in the table on page 1 can be hazardous to life forms if present at high levels. Nonessential heavy metals such as arsenic, lead, mercury, cadmium, and chromium are usually toxic to organisms at much lower levels than trace essential elements. Depending on the association that these nonessential elements may form with

natural geologic materials such as organic matter, other elements or minerals, and adsorbers (such as clays), these elements can range from being safe to being extremely toxic.

The elemental composition of plants, animals, and humans correlates with the geologic makeup of the Earth, and life has evolved reflecting these natural occurrences. The science of environmental geochemistry examines the interrelationship of life with the physical and chemical Earth.

Sources of hazardous element contamination

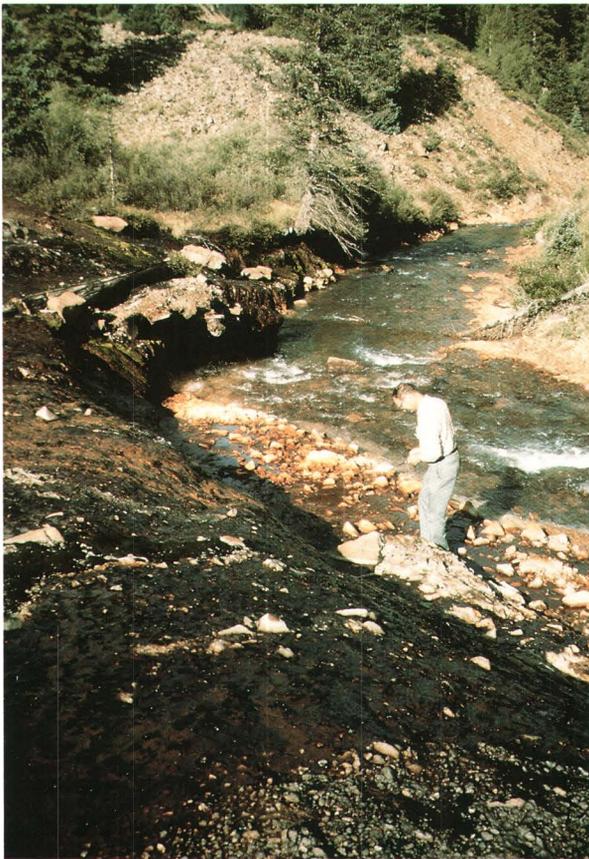
Because of growing public concern about environmental contamination, it is becoming increasingly important to better understand both the natural and human processes that control the movement of elements at the Earth's surface. Elements can be quite mobile in water, and the majority of our environmental problems are ultimately associated with the contamination of surface and ground water. The natural processes that control the behavior of elements in water are fundamental to the understanding, prevention, and correction of many environmental problems. Scientists strive to comprehend these natural and human processes and are improving models that predict with more accuracy the impact of both natural and human-related environmental changes.

When water comes into contact with rocks and soils, some of the minerals and organic substances dissolve and enter the natural waters. Forests and grasslands generally contribute only small amounts of these dissolved substances. However, it is possible for an area to contain unusually high concentrations of minerals, thereby depositing them to the waterways. For example, swamps and marshes often produce acidic and colored water. Other areas

that contribute natural pollutants to water are those containing rocks with sulfide minerals, particularly pyrite. When pyrite



Fluorine, emitted as a gas from phosphate-processing facilities in southeast Idaho, contributed to the death of these conifer trees.



Acidic, metal-bearing waters can form in mineralized areas that have not been mined. Here, natural iron- and aluminum-rich acidic waters flow into South Mineral Creek near Silverton, Colorado. The spring waters have precipitated a large terrace of iron hydroxide minerals (bottom). Mixing with the main creek waters raises the pH of the acid spring waters sufficiently to precipitate aluminum hydroxides, seen as white coatings on creek bed rocks (center of photo).

have both natural and human sources. These sources can range from a mineral deposit (natural point source) or industrial processing facility (human point source) to entire cities or several counties (nonpoint source).

Natural sources of toxic substances include rocks, volcanoes, sediments, and soils. For example, sedimentary rock in central Oklahoma contaminates ground water with arsenic, chromium, selenium, and uranium. In Africa, cooling magma beneath Lake Nyos in Cameroon produced carbon dioxide that bubbled up and suffocated 2,000 people in 1986. In the West Central United States, certain sedimentary rocks contain toxic amounts of selenium. Some plants can concentrate selenium in their tissue, which can result in livestock disease and death.

Human activities that add toxic substances to the environment include smelting, manufacturing, refining, chemical processing, fertilizer application, irrigation, and waste disposal. For example, prior to the passage of laws designed to protect the environment, the processing of metal ores created areas that were highly contaminated with heavy metals. These areas have subsequently been designated by the U.S. Environmental Protection Agency as hazardous waste (Superfund) sites. Areas affected by oil spills from tankers or wells are also classified in this group.

A large concentration of a substance commonly identifies a source of pollution but may not necessarily indicate a problem. In addition to the concentration, other characteristics of the substance must be considered. These characteristics include the amount of the substance released, the rate of release, its availability to organisms, and its residence time in a particular ecosystem. This information is essential to understand and to predict the activity of a substance under differing geologic and geochemical conditions. With this knowledge, the relation between the concentration of a substance and the magnitude of its environmental impact can be determined.

is exposed to oxygen and water, the water becomes acidic and often contains large concentrations of metals such as zinc, cadmium, and arsenic.

Inorganic substances are cycled naturally through our environment at concentrations that usually do not adversely affect plants and animals. However, the combination of some natural processes with human activities can increase these substances to harmful or toxic levels. Therefore, toxic substances may

The future—Possible problems and solutions

When it hurts

All too often a problem isn't recognized until something begins to hurt. That pebble in your shoe isn't a problem until it gets under your foot, but because of past experience, when you first notice the pebble, you can immediately anticipate future pain. For the solution to any problem we must first identify the problem, either from past experience or by new inquiry, and understand the process by which it came to be. Knowing the process suggests why the problem exists, and this understanding can possibly lead to a solution.

Geochemistry is for the birds

An irrigation project in the San Joaquin Valley, California, was created in the 1970's on a broad slope that extends from the foothills of the Coast Range to the San Joaquin River in the center of the Valley. Early in the project no one knew that toxic amounts of selenium had been transported for a very long time from rock sources in the Coast Range and concentrated in shallow ground water near the lower part of the slope. To control irrigation runoff and salt accumulation in the soils, this shallow ground water was drained away into evaporation ponds. During this draining process, the selenium was further concentrated by evaporation and accumulation into aquatic plants. A problem with the selenium was noticed when birds feeding on the plants began to die. Subsequent research showed that rainwater that had percolated through the selenium-enriched sedimentary rocks in the mountains had gradually dissolved the selenium. The element was then transported by the surface streams and through the ground water to the evaporation ponds.

A possible solution to this problem would be to speed up nature's own methods by either transforming the selenium to an insoluble form that is no longer

reactive or by flushing it to the ocean, where it would be effectively diluted. As a result of the research in the San Joaquin Valley, developers of new irrigation projects are aware of the potential environmental consequences of toxic amounts of selenium.

Geochemistry is for plants, too

Geochemistry touches both large-scale agriculture activities and home gardening either through natural environmental conditions or by the addition of fertilizers. Fertilizers are widely regarded as essential for favorable plant yield, but there is a negative side. Super-phosphate and limestone fertilizers are typically derived from natural rock deposits that may also contain significant amounts of metals. In Missouri, where fertilizer was heavily contaminated with lead, it was discovered that mine waste derived from the mining of lead hosted in limestone had been used as an inexpensive source of agricultural lime. In another example, natural forests in Missouri were cleared and planted with grass for cattle pasture. The soils were covered with lime to improve the grass yield, but the resulting increase in soil pH subsequently increased the uptake of certain metals by plants, which in turn adversely affected the health of grazing cattle.

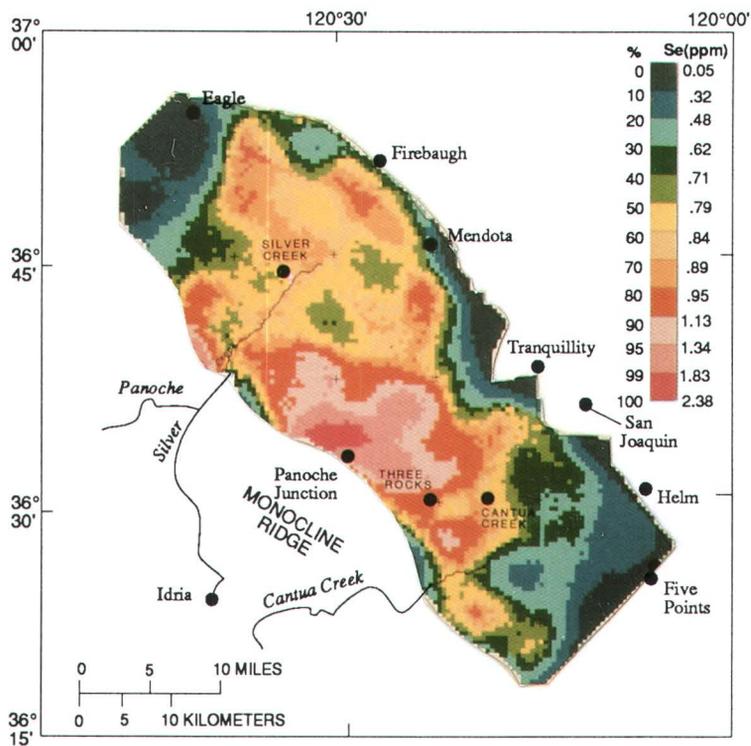
Sewage sludge and agriculture

Municipal sewage sludge can be an inexpensive source of agricultural fertilizer. Sewage, properly processed, is free of harmful bacteria. The resulting sludge contains plant nutrients, which crops respond to favorably, and organic matter, which improves the texture and water-holding ability of the soil. However, scientists know that heavy metals originating in industrial drainage concentrate in the sludge and can be toxic to either plants or animals. Studies near Denver, Colorado, in the early 1970's showed that

More about the chemistry and cycling of selenium

Like all elements, the form of selenium in rocks and soils governs its bioavailability (its uptake and incorporation into plant or animal tissue).

Although common in rocks and soils of the U.S., the form of selenium in Western U.S. geologic materials makes it far more bioavailable in arid and semiarid places like California and Nevada than in New York or Virginia. Therefore, environmental selenium as a human or animal health problem is only a concern in arid regions.



▶ The pattern of selenium (Se) concentration in soils collected in an area on the west side of the San Joaquin Valley, California. Selenium in the shale bedrock on Monocline Ridge was leached into the ground water and migrated east (downslope). Warm colors are areas of high soil selenium. Kesterson Reservoir, the site of selenium poisoning in waterfowl, is in the northern part of this region.

▼ California Aqueduct, Fresno County, California. Irrigation water from this source is used for agriculture throughout the San Joaquin Valley. The selenium leached from geologic formations accumulated in biota of the Kesterson National Wildlife Refuge. High concentrations of selenium resulted in wildfowl deformities and death.



hard, red, winter wheat absorbed significant amounts of cadmium, nickel, and other metals from sludge. Such metal absorption by crops fertilized with sewage sludge can be a problem. As a result, selection processes are now used to determine which crops may receive sludge fertilization and still have

minimal negative effects. Although there are some negative aspects to sludge fertilization, there are many benefits from the process. Successful use of sludge by both developing and developed countries demonstrates the advantages of its use as a fertilizer.

Geochemistry and responsible land use

Modern land-use managers are challenged to accommodate the increasing and often conflicting demands of potential users, while at the same time they must strive to preserve the integrity of natural resources. Accurate site-specific geochemical data are critical for responsible land-use decisions. The data must define the physical and chemical characteristics of the near-surface environment (the area from the Earth's surface down to the bedrock) and must describe the natural processes that form and modify these characteristics. Land-use decisions should be compatible with these natural processes or should include strategies to reduce any negative impact on the land.

Geochemical studies by USGS scientists have defined the causes and extent of the selenium problem in California. However, the initial gathering of geochemical data could have helped managers lessen this environmental problem. Additional irrigation-related problems include the leaching of pesticides, herbicides and other potentially toxic trace elements, and loss of soil fertility through salt buildup (salinization). Land managers who consider geochemical and other earth-science data in their decisions can better anticipate or remediate these potential problems. Such data include the local topography, climate, and hydrology, as well as the distribution and characteristics of the region's soils and bedrock.

Geochemical processes

Many biogeochemical processes influence the quantity and distribution of elements in our environment. The degree of influence of a particular process varies with the type of element, the ecosystem of interest, and the chemical conditions of the system.

The processes that scientists know exist and have studied include:

- **Biological transformations**—Sunlight and nutrients such as carbon, nitrogen, and phosphorus are transformed through photosynthesis in plants. Other trace elements such as boron, copper, iron, manganese, molybdenum, and zinc are also incorporated into plant matter during photosynthesis. When plants die, microorganisms such as

bacteria decompose the plant, and the elements are released back into the atmosphere, soil, and water.

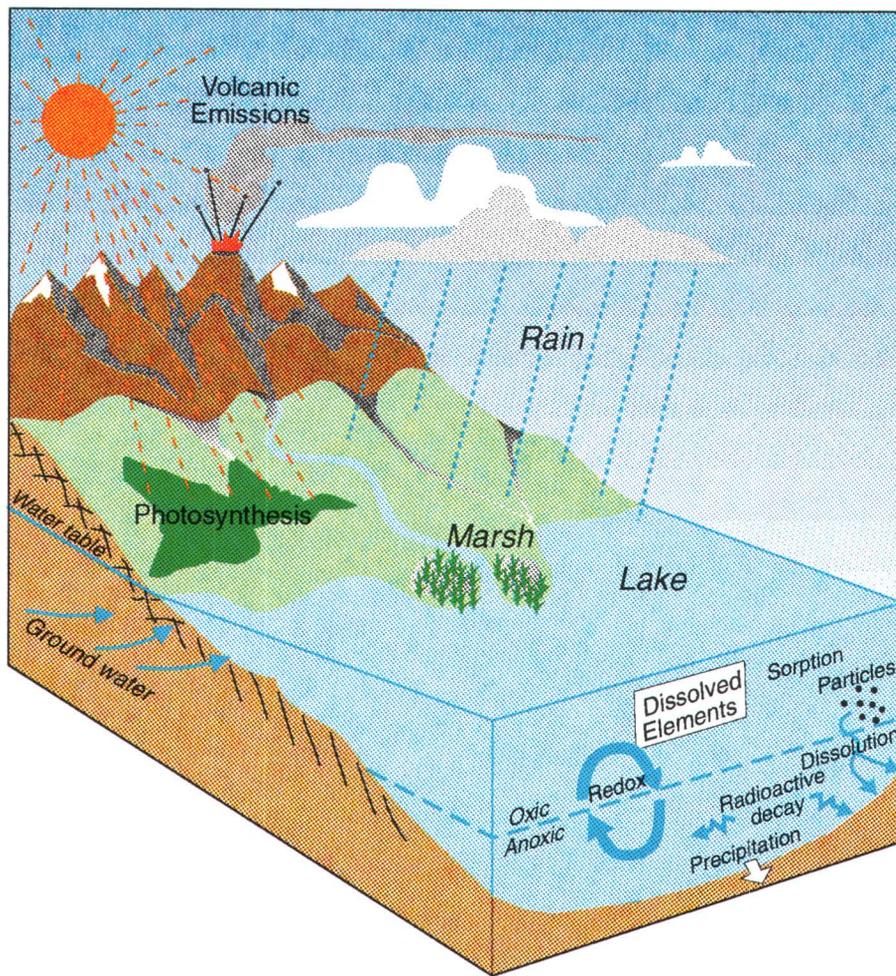
- **Oxidation/Reduction (Redox) reactions**—These reactions change the chemical and physical form of elements through the exchange of electrons. For example, iron exists in a solid form (i.e., rust) when oxygen is

present and in a dissolved form in water when oxygen is absent.

- **Radioactive decay**—These reactions involve the spontaneous release of gamma rays and electrons. The rate of this decay is known for radioactive elements and can be used in geochemical studies to determine how the rate of various processes affects the distribu-

tion of elements in an environment.

- **Scavenging or sorption**—These processes involve the physical or chemical attachment of dissolved elements to the surfaces of particles. For example, in lakes certain toxic dissolved elements such as arsenic can be adsorbed onto sinking particles or bottom sediments. In the adsorbed



◀ The general cycle of element mobilization, transport, and deposition. Elements that are mobilized through processes listed below are both physically and chemically transported. They eventually are redeposited in lake and ocean sediments to be locked away until mobilized once again.

state these elements are effectively removed from being further circulated through the system.

- **Precipitation**—This process relies on the chemical conditions of a solution and reactions whereby dissolved elements form solids. Many ore deposits were formed by the precipitation of elements from hydrothermal solu-

tions. Certain base-metal ores (copper, lead, and zinc) form in this manner.

- **Atmospheric deposition**—After being carried by wind, elements are deposited by rainfall or on dust particles and incorporated into plants, soils, and water.
- **Transport by water**—Rivers, streams, and ground water can supply and remove

particles and dissolved elements from aquatic systems such as aquifers, wetlands, and lakes. The mixing of waters can then redistribute dissolved elements in an environmental system.

- **Volcanic emissions**—When volcanoes are active, they produce gases and lava, thereby bringing elements located deep

within the Earth to the surface.

- **Weathering of rocks**—Rocks that are weathered chemically and are mechanically broken down into smaller pieces form soils, and the elements are redistributed.

Many of these processes are linked to one another. Therefore, to better understand them, researchers use

sophisticated geochemical tools to explain the complicated, intertwined relationships. These tools include mathematical models, advanced sampling and analytical techniques, and both laboratory and field studies, which all help to identify the processes.

Geochemical Processes in the Environment

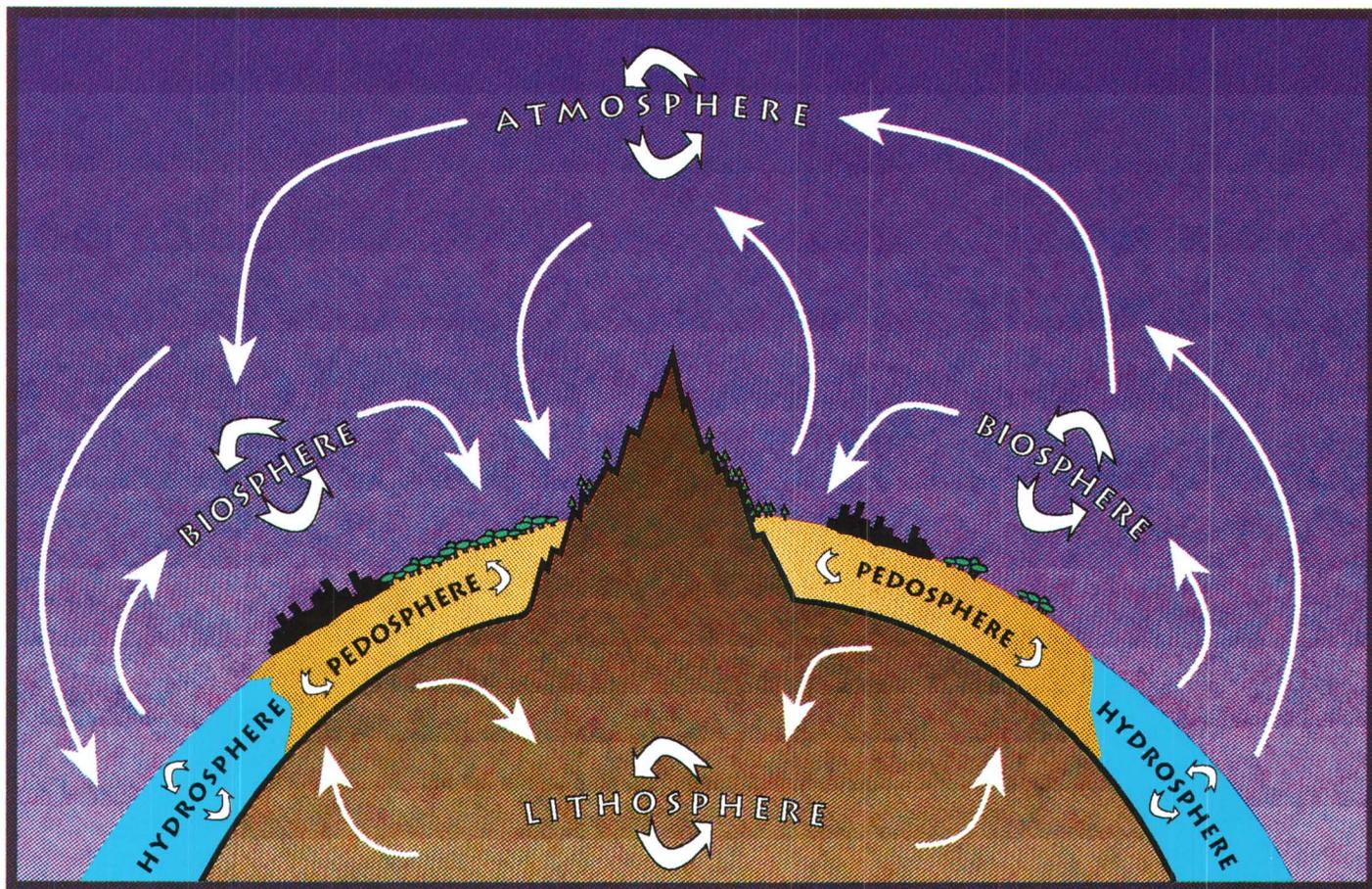
The global perspective

- *Lead from a smelter poisons nearby children*
- *Power plant emits sulfur dioxide causing acid rain*
- *Arsenic from mine tailings pollutes local water supply*

Newspaper headlines such as those above describe a few of the pollution problems occurring throughout the world. Human activities can have an environmentally destructive effect on the world as a whole. For instance, the Chernobyl nuclear reactor disaster of 1986 demonstrated that there are no political or geographical boundaries to the distribution of harmful elements and compounds. During the 20th century, the dispersion of numerous elements, largely due to human activity, has been “recorded” in layers of polar ice and snow. Specifically, these recordings have shown the rise of the Industrial Revolution and the global circulation of metal contaminants such as lead and mercury. Synthetic compounds have also been widely dispersed. Some Arctic natives have been exposed to unusually high levels of polychlorinated biphenyls (PCB’s) by consuming fish and aquatic mammals that seem to have the material concentrated in their tissues. PCB’s are very toxic byproducts of the

modern plastics and coolant industries that remain in the environment for a very long time. This is one example of atmospheric and hydrologic processes that distribute elements and compounds around the planet. As a result, a pristine environment is now only a relative term.

Aspects of the major biogeochemical cycles of elements such as carbon, nitrogen, phosphorus, and sulfur vary from location to location but still must be viewed in a global perspective. An example of the importance of viewing these processes as a whole is the current global warming problem. Both human activities and natural processes have contributed to global warming. Human influences include power plants, factories, waste disposal, and the processing of raw materials. The natural biogeochemical cycling of elements has also played a role in global warming. Scientists must understand the complex linkages among biogeochemical cycles, and, in so doing, their studies must encompass four dimensions: the two dimensions of the Earth’s surface, plus depth and time. Hence, *environmental geochemistry is the study, in time and space, of the concentration, total quantity, and chemical form of elements and the physical and chemical processes that control their mobility and transformation in our environment.*



The Earth can be thought of as having five interconnected regions or spheres of chemical, physical, and (or) biological

activity, each of which plays a role in the mobilization, transport, and deposition of chemical elements.

Heavy-metal mobilization, transport, and deposition

Many elements that are a natural part of mineral deposits, rock formations, or soils are easily mobilized into water as a result of specific chemical conditions. The degree that an element is dissolved and its ultimate fate are dependent on the geochemistry of the specific element and the geology of the material from which it came. Iron, manganese, copper, lead, arsenic, and cadmium are quite often part of mineral deposits and are mobilized naturally or as a result of mining and the chemical reactions that cause acidic mine-drainage waters. These elements and many others can also be found in ground water,

surface water, and soils as a result of industrial uses. For example, arsenic, which is often a byproduct of gold-ore refining, has been used extensively in insecticides and herbicides.

The distribution and effect of arsenic in the environment from mining and industrial waste continue to be an important focus of research. As a result of mining, large amounts of arsenic-bearing wastes are found on the Clark Fork River in Montana and the Cheyenne River system in South Dakota. Following mining activities, the arsenic was mobilized by weathering processes and found its way into surface and ground water and aquatic life forms.

Baselines and backgrounds— What's natural and what isn't

What is a baseline?

A baseline is computed as two deviations about the mean. Two deviations include about 95 percent of the area of the distribution under a normal frequency curve.

Backgrounds and baselines are generally developed by: (1) defining the population (sample) to be described; (2) collecting samples that represent the population; (3) analyzing the samples for the constituents of interest; and (4) computing the range that represents the baseline.

How can this range be used to determine whether a single sample is unusual in composition? For example, if several samples of soil are collected and analyzed, and most of them have concentrations of elements outside of the expected 95-percent range for soils that are representative of the general area, then there is a good chance that these are unusual samples, perhaps representing some type of environmental contamination.

Regulatory limits for safe levels of elements in water and foodstuffs are established by the U.S. Environmental Protection Agency and the U.S. Food and Drug Administration. However, there are generally no regulatory limits that scientists can refer to when dealing with plants, soils, rocks, and sediments. Therefore, to determine whether a plant, soil, rock, or sediment contains a "high or unusual" quantity of a specific element, it is necessary to determine what quantity is "normal or usual." These levels are referred to as background or baseline measurements, but they may be somewhat different.

A *background* measurement represents natural concentrations of an element in natural materials that exclude human influence. This measurement represents an idealized situation and is typically more difficult to measure than a baseline. True backgrounds may be obtained by sampling and analyzing items that have a minimum of human influence such as tree rings, deep glacial ice cores, or layers of sediments from lake or ocean floors.

A *baseline* measurement represents concentrations measured at some point in time and is not generally a true background. Baseline concentrations are typically expressed as a range, not a single value.

The three objectives that are generally common to all background and baseline studies are:

- **To describe the chemical characteristics and variation of an environment**—The study should tell something about the composition of the materials sampled as well as their distribution or pattern across the landscape.

- **To assess the extent or intensity of environmental alteration**—Baseline studies should also evaluate the changes in the environment due to human activities.

- **To provide basic information necessary to study environmental processes**—The background information generated from environmental studies may show patterns for a certain group of elements. The element distribution or pattern across the landscape, together with information regarding the area's geology, soils, and plant communities, provide useful data that help explain processes such as element mobilization, transport, and deposition.



Collecting slash pine needles to determine baseline element concentration values. In the United States, an unusual form of slash pine is found only in south Florida near Everglades National Park. Slash pine is being threatened by agriculture, housing developments, and air pollution.



From the farm fields' checkerboard pattern south of Lake Okeechobee, to Miami's speckled concrete patterns on the eastern Atlantic coast, this Landsat (satellite) photograph shows the human impact on the environment. Color enhancement helps to delineate land-use patterns and, over time, can track vegetation changes

within Everglades National Park (lower left). These changes are caused by natural (Hurricane Andrew) and human influences (air contamination from Miami, agriculture, and heavy industry). (Reproduced with permission from Earth Observation Satellite Co., Lanham, Maryland, USA.)

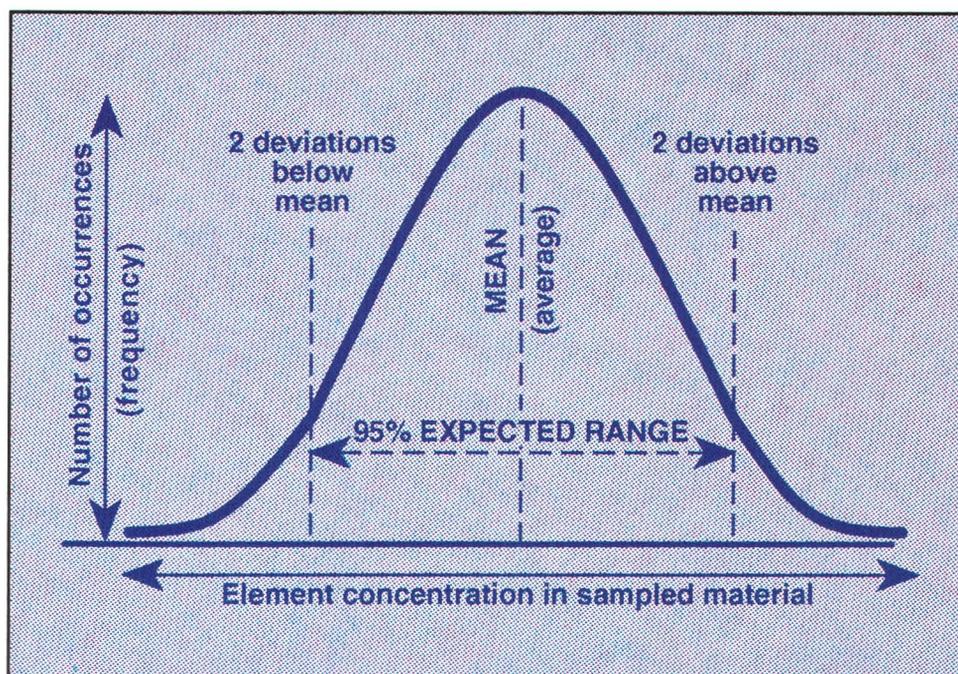
New technology provides tools for the geochemist

The defining and understanding of problems in environmental geochemistry often require accurate measurement of both organic and inorganic substances. Questions such as “What substances are in this sample?” and “How much of it is there?” are answered by using modern analytical techniques. Two of the most important techniques are gas chromatography-mass spectrometry (GC-MS) and inductively coupled plasma mass spectrometry (ICP-MS). GC-MS is used to identify and quantify organic compounds, where-

as ICP-MS is used to identify and quantify inorganic substances. Both techniques are indispensable to the geochemist.

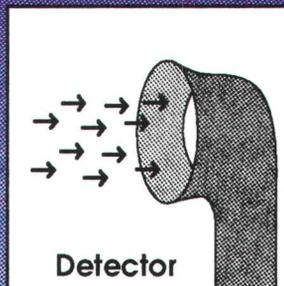
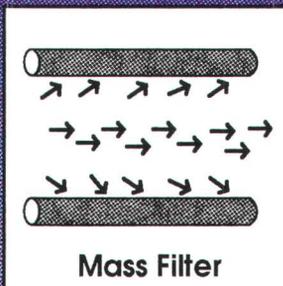
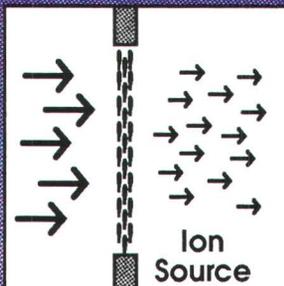
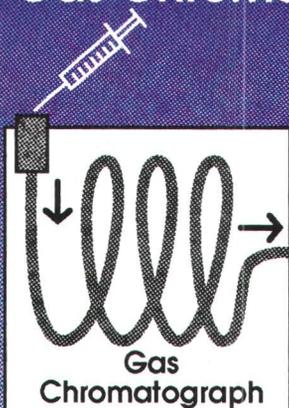
Soils, sediments, rocks, air, and water can contain a large number of *organic substances*, both natural and manmade. Often they are present as complex mixtures made up of dozens to many hundreds of individual molecules. To find the needle (a pollutant of interest) in the haystack (a complex mixture of organic compounds), GC-MS is used. Typically, a very small amount of a sample is

How is a geochemical baseline expressed? It is often expressed not as a single concentration value but as a range. This range is based on a normal frequency distribution of the concentration values found in some sample material and is usually plus or minus two deviations about the mean value (95 percent expected range).



Gas Chromatography and Mass Spectrometry:

One Method of USGS Sample Analysis



Sample identification begins when liquefied material is injected into the column or coil of the gas-chromatograph. Based on their relative sizes, the various components of the sample are retained at different rates by the presence of a gummy substance.

Next, the separated components of the sample pass one by one through an ion source where they are bombarded by an electron beam. This beam breaks the sample into even smaller, ionized fragments.

The ionized fragments then pass through a mass filter where they are further separated based on their mass-to-charge ratio. Only a small proportion of the ion fragments need to make it through the mass filter.

Finally, the detector records the electrical charge and arrival time (as established by step one) of each passing portion of the sample. This information is then sent to a computer, which identifies each component of the sample. A list containing each component of the sample is then provided to the analyst.

injected into the GC-MS instrument. This sample is vaporized in an instant and each individual molecule type travels through a narrow column at a different speed. Each molecule comes out of the tube and goes into the mass spectrometer, an instrument that determines molecular weights, where an electron beam breaks the molecule into several pieces. By studying the pattern of the pieces and their abundance, the scientist can tell what the molecule was and how much of it there was in the sample. This, in turn, helps

assess the concentration of the molecule in the mixture.

When an environmental study is concerned with *inorganic substances*, ICP-AES or ICP-MS is the analytical technique of choice. Most elements in the periodic table can be ionized at high temperature in a "plasma" (high-temperature ionized gas), which subsequently is sent into the mass spectrometer where signals for individual atoms are detected.

Examples and Case Studies

Plant and animal health

Molybdenum can be too much of a good thing

Molybdenum is a metallic element probably best known as a substance that hardens and strengthens steel. It is also used in a dry lubricant that is resistant to high tempera-

tures. However, it is an essential element to plant and possibly even animal health.

At least five distinct enzymes (essential proteins) in plants contain molybdenum. Two of these enzymes serve to metabolize nitrogen, a major plant nutrient. Members of the legume family—for example, clover and alfalfa—are particularly rich in molybdenum because their roots harbor nodules of the bacterium *Rhizobium*, which biologically transforms nitrogen.

One negative aspect of molybdenum is that in large concentrations it interferes with the absorption of copper, an essential element; therefore it may have toxic effects on certain livestock when ingested in large amounts. The resultant effect, or illness, is molybdenosis. The symptoms of the illness include: anemia, depressed growth, diarrhea, poor reproduction, bone malformation, nervous disorders, and loss of normal hair color. For example, the hide of Black Angus cattle turns a mouse-gray as a result



The nutritional imbalance of copper to molybdenum in the diet of cattle (a disease known as molybdenosis) produces symptoms such as hair discoloration and loss, and weight loss. The steer above is healthy; the steer to the right is suffering from molybdenosis. (Reproduced with permission from Dr. Verle Bohman, Professor Emeritus, Department of Animal Sciences, University of Nevada, Reno, Nevada.)



of molybdenosis. Similarly, high levels of molybdenum in the diet of sheep may lead to defective nervous systems in lambs. However, if treated early enough, molybdenosis is reversible through corrective nutrition.

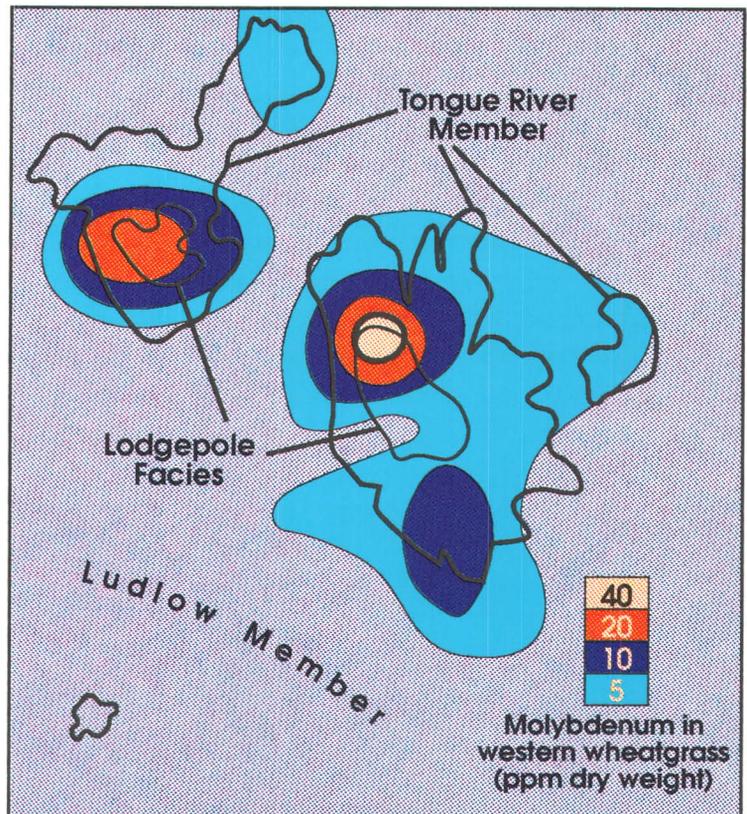
Molybdenosis, cattle, and lignite

A low-grade coal called lignite has been strip-mined for decades in the northern Great Plains. Lignite contains appreciable levels of molybdenum and uranium derived from volcanic rock deposits. Ranchers in northwestern South Dakota reported problems that resembled molybdenosis in cattle pastured around an abandoned lignite strip mine. Results in the area of Flint Butte showed that the range grasses contained very high levels of molybdenum, but only in areas near exposed lignite. The high levels of molybdenum resulted from lignite that was naturally exposed in the environment as well as from lignites exposed during surface mining. The molybdenum was removed from the lignite through weathering processes, transported by surface-water runoff to the nearby pastures, and taken up by the range grasses.

Molybdenosis and humans

In developed countries such as the United States, where food production and distribution are widespread, and produce grown in one region is often shipped to another, molybdenum-related nutritional problems in humans probably do not exist. However, occurrences of molybdenosis have been reported in some developing countries.

One such incidence occurred in southern India where construction of a large dam and the resultant reservoir raised the water table in the surrounding farming district.



The pattern of molybdenum concentration in western wheatgrass collected in the Flint Butte area of South Dakota. Highest concentrations were found to correlate with outcrop of uranium-bearing lignite (a soft coal).

Subsequently, molybdenum levels increased in the major crop, sorghum. The local inhabitants rely on sorghum as their dietary staple, and following consumption of the food, some individuals developed *genu valgum* (knock-knee), a crippling bone deformity affecting young people. Although this problem occurred in a relatively small region, the impact of the disease on the local population was serious.

Radon, uranium, and the environment

Radon is a radioactive, gaseous element that is naturally occurring and results from the radioactive decay of uranium and thorium. Uranium and thorium are contained in natural geologic materials and are often concentrated, over geologic time, under certain environmental conditions (for example, in geologic formations high in organic matter such as coal and peat and sediments high in clay). Public health concerns have focused recently on radon in homes constructed over so-called "high-risk" geologic regions. The USGS has produced radioactivity maps that

can help identify geographical regions that have the potential for high radon in the environment (see map below).

In addition to being a public health concern, radon has been used in various scientific disciplines. It has been used to explore for uranium, monitor the movement of atmospheric air masses, trace the mixing of streams and oceans, map geologic faults, predict earthquakes and volcanic eruptions, and evaluate air movement in caves. This latter use helps scientists determine how caves are formed.



Uranium map based on radioactivity

Radioactivity maps give an indication of the uranium levels of surface

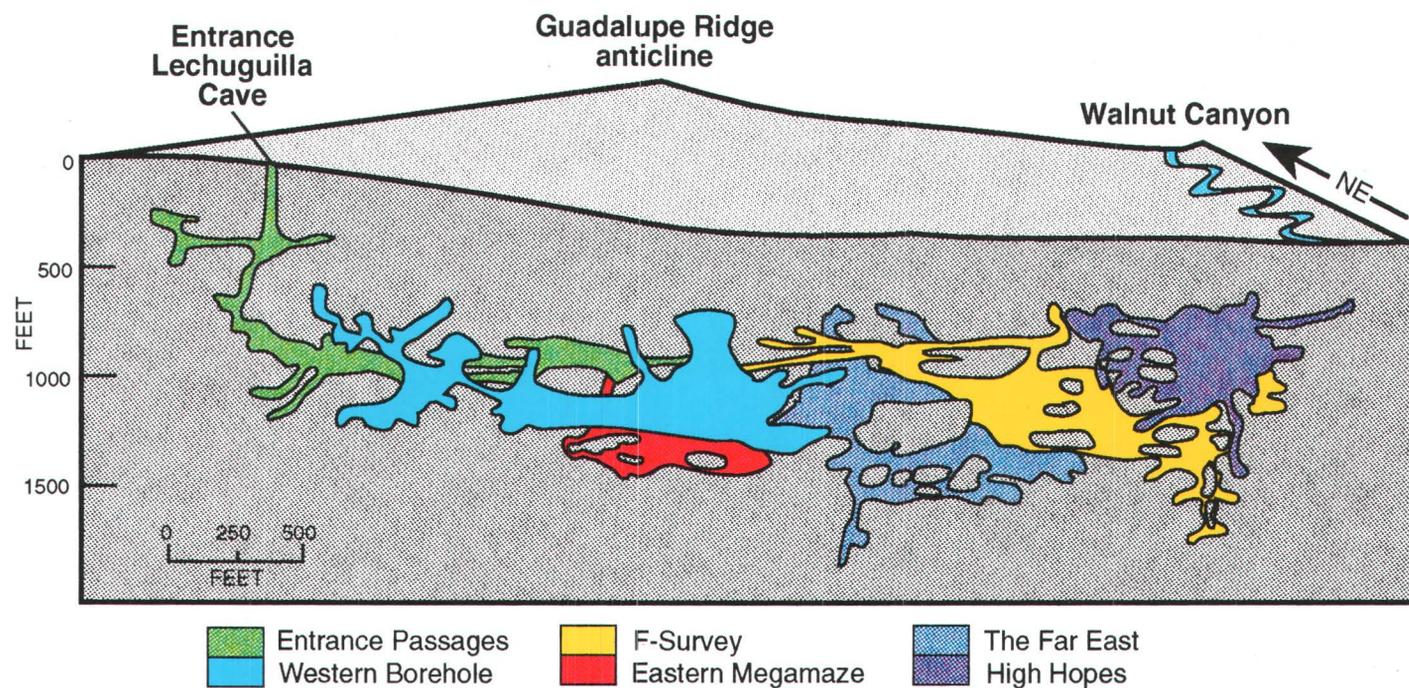
materials. The most common type of radioactivity map is an aero-radioactivity map, which is based on radioactivity measurements made from an aircraft flying at low

altitude with instruments that measure the radioactive energy radiating from the ground.

Regions of the country that are both high and low in radioactivity can be identified in this

map. For example, west-central Ohio shows moderately high radioactivity due to the spreading of uranium-bearing black shales over the area by glaciers, whereas the north-

west is low due to large areas that are covered by volcanic basalts that are low in uranium. (Warm colors indicate high amounts of uranium; cool colors indicate low uranium content.)



Six different microclimatic zones are shown for Lechuguilla Cave in Carlsbad Caverns National Park, New Mexico. Radon was used for the first time to map and characterize these multiple microclimate zones (air circulation cells) in the various cave areas in conjunction with observed airflow data. Suspected sur-

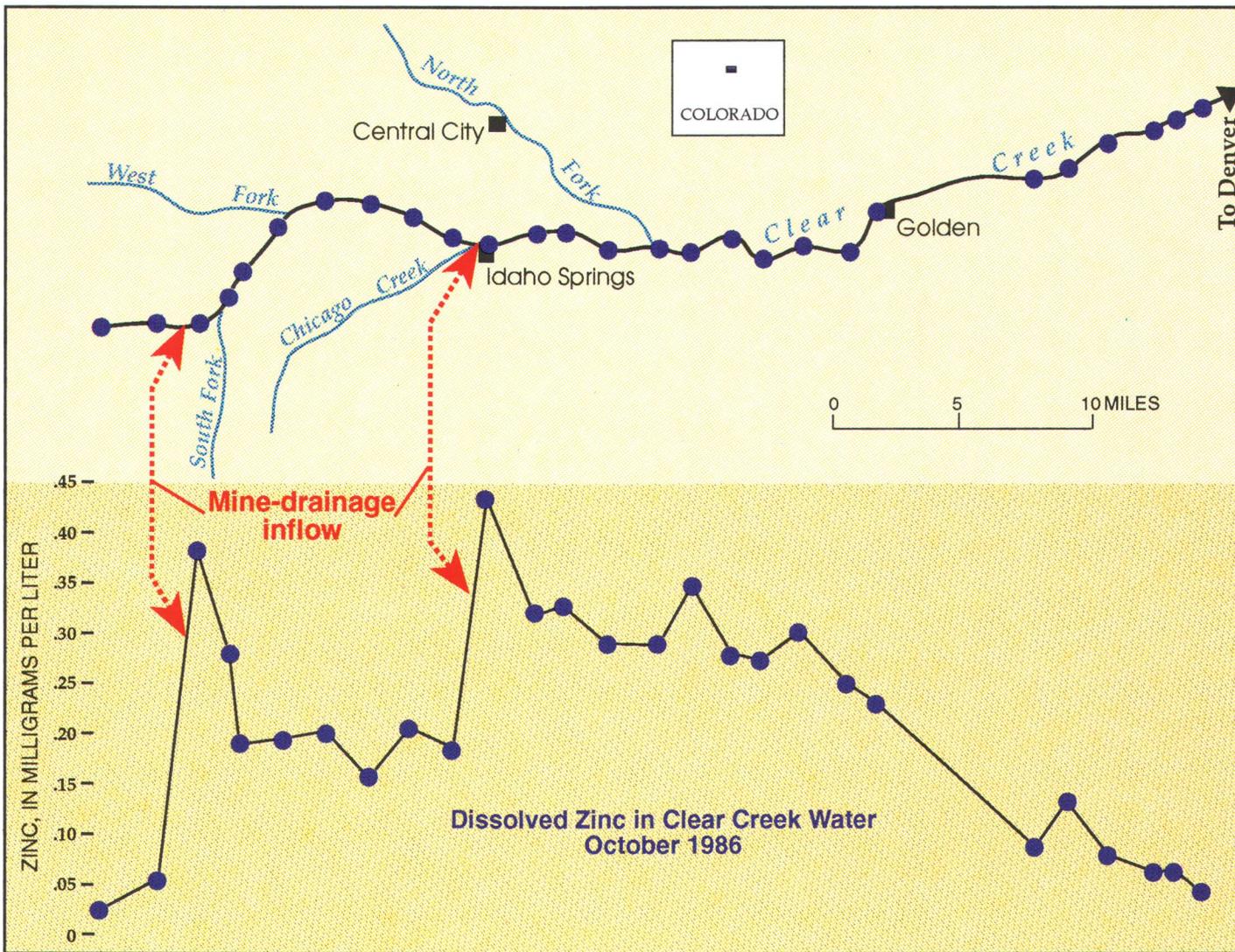
face connections contribute fresh air to remote cave areas as demonstrated by low radon values surrounded by higher values, as well as the presence of mammalian skeletal remains, atmospheric-level carbon dioxide concentrations, cooler than normal temperatures, and surface topographic relationships.

Mine drainage

What is it?

Mine drainage is metal-rich water formed from reactions between water and rocks containing sulfide minerals (types of metal-sulfur compounds). This runoff is often acidic (has a low pH) and frequently flows from areas where ore- or coal-mining activities have exposed rocks rich in the sulfur-containing mineral, pyrite. Metal-rich

drainage can also occur naturally in mineralized areas. Potential problems associated with mine drainage include contaminated drinking water and disrupted growth and reproduction of aquatic organisms. The bottom of streams contaminated by mine drainage is commonly coated with red, orange, or yellow sediment, as seen in the photographs on page 19.



The USGS is currently studying a number of watersheds in Colorado to understand the impact of mine drainage on water quality. For example, Clear Creek, a major source of water for municipalities and industry in the Denver metropolitan area, receives drainage water from several historic mining districts.

This plot demonstrates how the drainage impacts dissolved metals in the water along Clear Creek. Zinc, copper, manganese, and iron show variations in concentration that reflect the input of mine water.



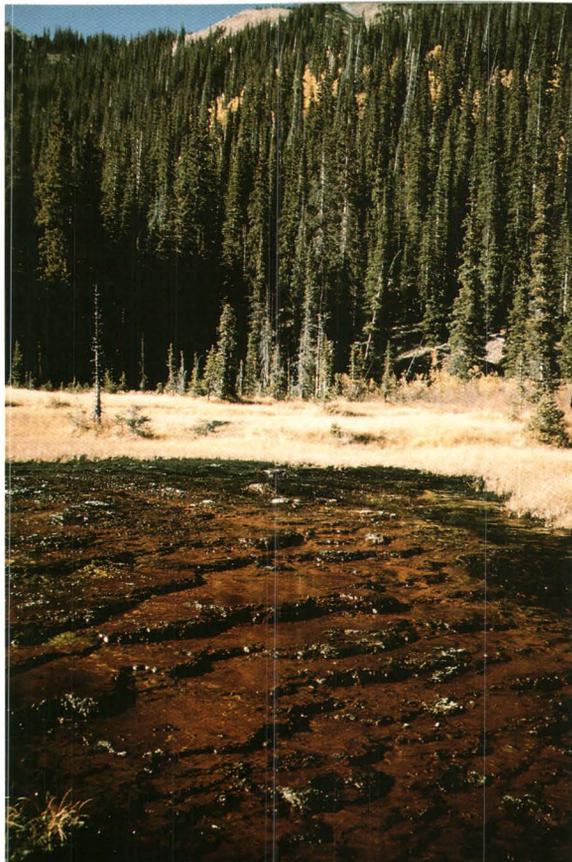
◀ Iron-, zinc-, and copper-rich waters draining from the Rawley Tunnel, Bonanza District, Colorado. The waters emanate from a collapsed mine adit in back of the green shed (top center), traverse mine dump material (center), and flow into Squirrel Creek (bottom). As the mine waters flow along the ground surface, they become oxygenated and precipitate red, orange, or yellow iron hydroxide minerals on the stream bed, imparting the “bleeding ground” appearance common to many mine drainages.

▼ Acidic, metal-bearing waters can also form in mineralized areas that have not been mined. Here, natural iron- and aluminum-rich, acidic spring waters precipitate terraces of iron hydroxide minerals near the headwaters of the Alamosa River, southwestern Colorado. The spring waters drain pyrite-rich mineralized rock that has not been subjected to mining. The lobate terraces are approximately 2-3 inches high and up to 5 or 6 feet wide.

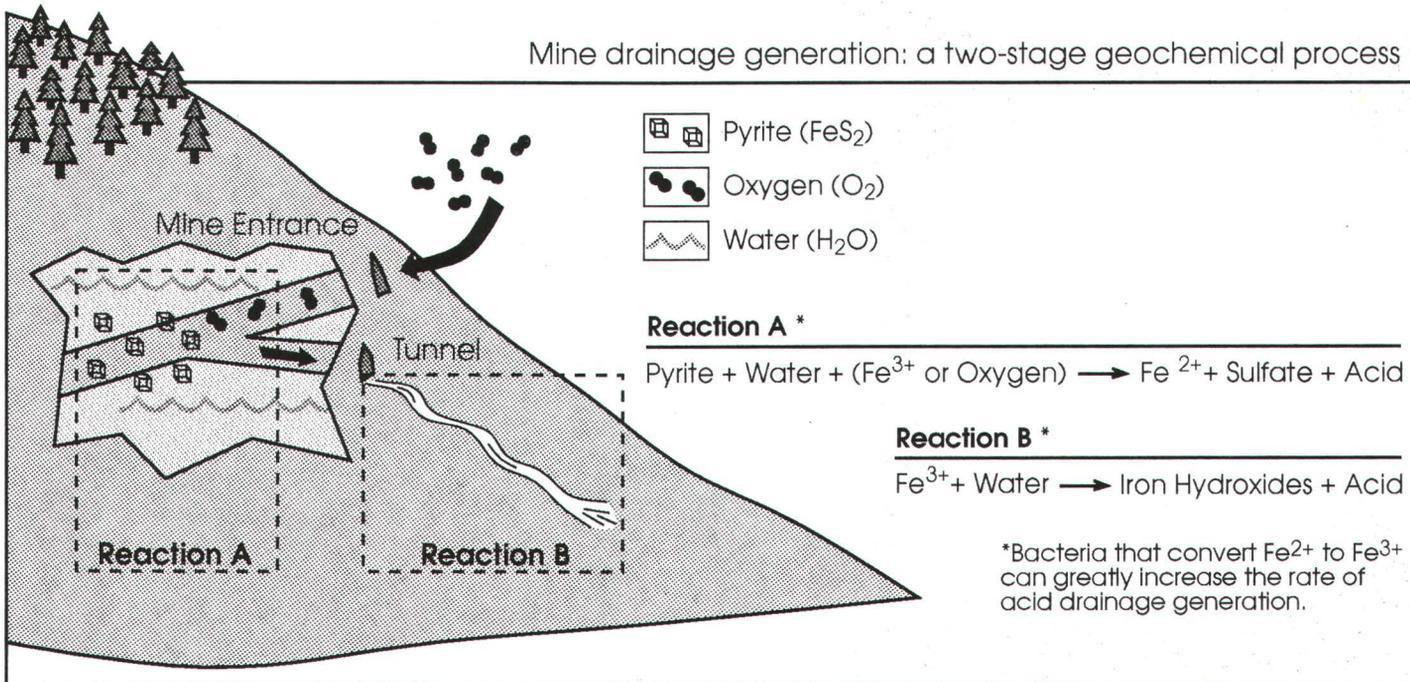
How does mine drainage occur?

Mine drainage is formed when pyrite, an iron-sulfide mineral (FeS_2), is exposed and reacts with air and water to generate sulfuric acid (H_2SO_4) and dissolved iron. Some or all of this iron can precipitate to form the red, orange, or yellow sediment in the bottom of streams containing mine drainage.

The rate and degree by which acid-mine drainage proceeds can be greatly increased by the actions of certain bacteria. As a result, some mine drainage can be more acidic than vinegar. During acid-mine drainage, the generated acid and iron can cause oxidation and dissolution of additional pyrite and other sulfide minerals containing metals such as lead and copper. These metals are



Mine drainage generation: a two-stage geochemical process



then released into the water in addition to the initial amounts of acid and iron. Furthermore, even more chemical elements can be released when the rocks that are actually sitting in the water are attacked by the acidic solution.

Geochemists, chemists, and geologists are trying to understand factors that control the composition of mine drainage. They have found that some mine drainages are acidic and some are not; some contain a larger quantity of metals than others. Differences in the chemical composition of mine drainages are a result of several geochemical, chemical, and geological factors such as the types and amounts of minerals (particularly pyrite) in the rock and the amount of oxygen in the water. Once the factors that control mine-drainage composition are understood, this information can be used to

predict the composition of future drainage and as an evaluation tool for possible remediation techniques.

What can be done to clean up mine drainage?

It is difficult to stop the formation of mine drainage because it requires keeping air and (or) water away from the exposed rocks. Scientists are testing prevention techniques such as: (1) trying to find ways to hinder the bacteria that speed up the chemical reactions that generate mine drainage, and (2) grouting fractures in abandoned mines to prevent the inflow of oxygenated ground waters. They are also working to understand how wetlands can be used to scavenge metals and neutralize acid in mine drainage.

Air pollution and biogeochemistry

The temperate forest, one of the most productive ecosystems in North America, is particularly sensitive to several types of air pollution. The ability of this ecosystem to efficiently cycle nutrients results in high forest productivity. Anything that causes a disturbance (stress) in a particular biogeochemical cycle (for example, the cycling of sulfur or nitrogen from atmosphere to soil to plant and back to the atmosphere) will affect the whole system.

Many areas of North America and Europe are experiencing widespread forest decline—but is this caused by air pollution? Shifts in forest ecosystem productivity are natural phenomena and can be accelerated or accentuated by the introduction of stresses in the system. These stresses can be natural,

such as precipitation changes, insect infestations, and fires, or can be influenced by man-made disturbances, such as forest clearing, soil erosion, and air pollution.

Three basic types of air pollution can cause ecosystem stress:

- **Acid precipitation**—caused by sulfur dioxide and other acid-forming substances from fossil-fuel-burning sources (coal-fired power plants) being released into the atmosphere.

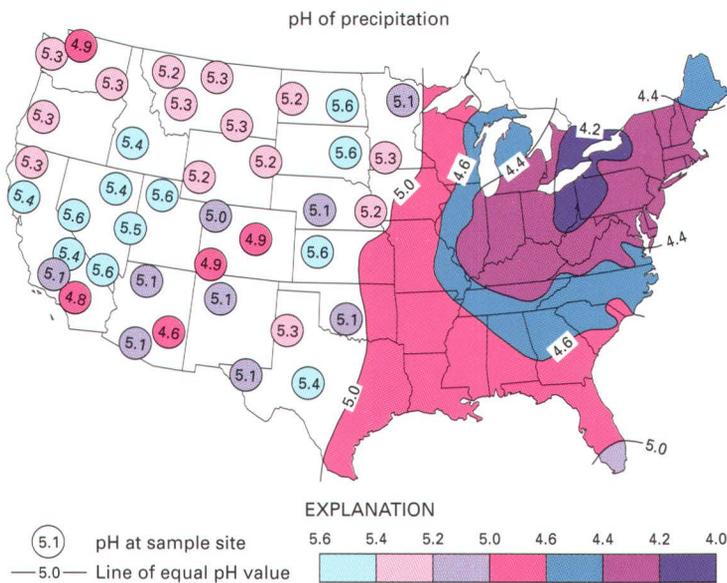
- **Oxidizing and chemically reactive substances**—for example, ozone, carbon monoxide and dioxide, and complex organic compounds (collectively known as “photochemical” compounds) also originate from the combustion of fossil fuels.

- **Heavy metals**—such as lead, copper, zinc, nickel, cadmium, cobalt, and chromium that are released by many industrial activities.

These three types of air pollutants produce different levels of stress for both individual organisms and for the ecosystem as a whole. At low levels, forests act as receptors or filters for pollutants. For example, it may not be possible to measure the damage caused by a toxic metal, such as copper or mercury, but the accumulation of the metal or its movement through the system may be easily measured. At intermediate levels the stress that pollutants bring to the system can be observed in particularly sensitive species and may be manifested as metabolic



Plantations of seedlings like these of slash pine in Everglades National Park, Florida, are used to monitor the effect of deteriorating air quality on the local vegetation.



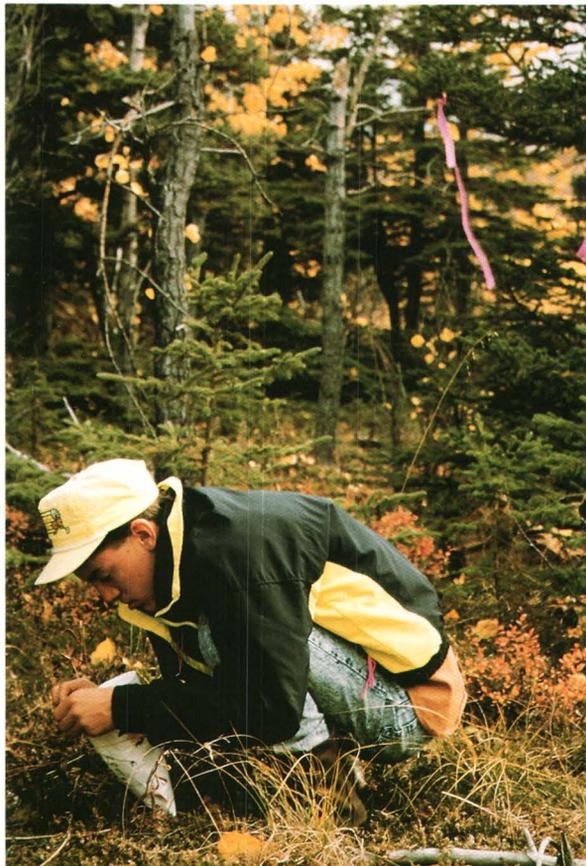
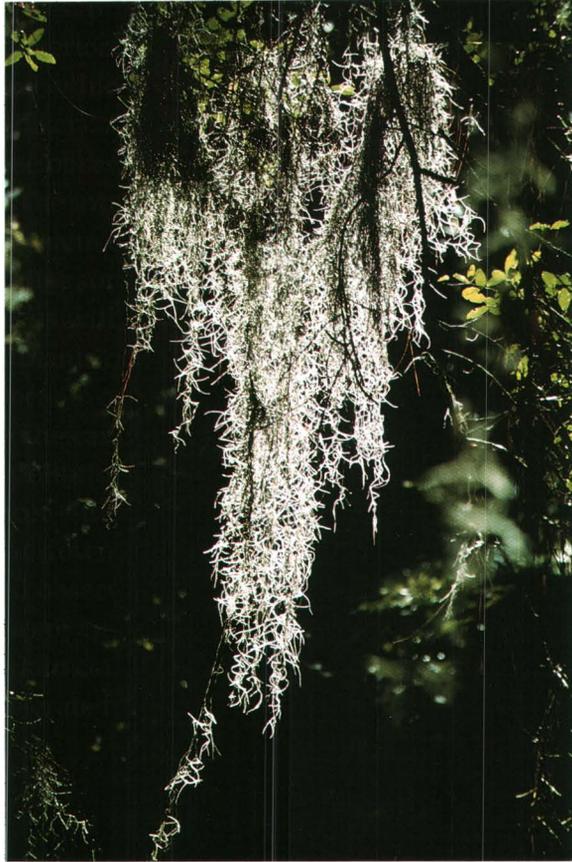
▲ Modern emission-control equipment, such as scrubbers for sulfur and precipitators for particulates, have made this smoky scene of a coal-fired power plant in Wyoming much less common.

◀ “Acid Rain”—This map shows the tendency of precipitation in the northeastern United States to be more acidic in general than other broad regions of the country. Scientists attribute this to emissions from factories and power plants that are high in sulfur.

changes, predisposition to disease, or nutrient overload (for example, ammonium deposition, which acts as a growth stimulant or fertilizer). At high levels, pollutants can cause observable symptoms and plant death.

The introduction of heavy metals into an ecosystem can be easily measured, and because some plant species like mosses and lichens will actually accumulate these metals, plants can serve as “biomonitors” that reflect air-quality changes.

The cause of forest decline and the role of air pollution have been compared to cancer—the result of multiple stresses that wear down components of an ecosystem until observable changes occur. The three types of air pollution mentioned on page 21 work in conjunction with natural stresses to accelerate forest decline.



▲ *Spanish moss, pictured here in South Carolina, is not a true moss at all, but makes an excellent biomonitor and estimator of overall air quality because it is an epiphyte that normally grows on other plants and does not obtain its nutrients from either its host or the soil but from the atmosphere.*

◀ *Like Spanish moss, lichens and true mosses are excellent biomonitors of overall air quality because the species (collected here by a USGS volunteer in Denali National Park and Preserve, Alaska) obtain all of their nutrients from dry and wet deposition from the atmosphere.*

Volcanogenic and greenhouse gases

The atmosphere is a global reservoir that mixes across state and national boundaries, across oceans, and between hemispheres. Natural environmental processes (geological, biological, and geochemical) produce the greenhouse gases carbon dioxide (CO₂) and methane (CH₄). These gases, along with water vapor, are primarily responsible for atmospheric warming, which is the “greenhouse” effect. We know there is a greenhouse effect based on at least three types of findings:

- **The Earth would be approximately 30 degrees Celsius cooler** if it did not have its present atmosphere; as a result, all the water on the surface of the Earth would be frozen.
- **Using the known atmospheres of the other planets** (Venus and Mars in particular), we can predict their surface temperatures based on their amounts of greenhouse gases, gases which are the same as those found on Earth.
- **The record of past atmospheric gases** (CO₂ and CH₄) trapped in ancient ice core samples from glaciers shows correlations with past climates (historic records).

Periodic geological events, such as volcanic eruptions, add large amounts of carbon dioxide and other gases to the atmosphere. These gases tend to enhance the greenhouse effect. Volcanoes also add large amounts of aerosol particulates (sulfates and ash) that seem to cool the atmosphere. These events can be monitored but cannot be accurately controlled or predicted. USGS scientists at various observatories are monitoring these volcanic emissions in an attempt to better understand the processes.

Biological processes produce methane in certain geochemical environments, such as wetlands and freshwater marshes, where there is an absence of oxygen (anoxic). These methane emissions are a result of bacterial metabolism (decay) of organic matter. Warming of the atmosphere, land, and oceans by carbon dioxide and methane would result in sea-level rise due to thermal expansion and glacial melting, and coastal regions, including marshes, would be flooded.

Salt marshes also produce methane, but not as much as freshwater marshes. This is because microorganisms known as “sulfate reducers” are abundant in salt marshes and inhibit the methane-producing microorganisms. Brackish marshes (water with a salinity between that of sea water and fresh water) emit 25 to 50 percent less methane than the freshwater marshes they succeed. Thus, as salt waters flood and destroy freshwater marshes, less methane is produced.

The Gulf Coast of Louisiana has been experiencing coastal-wetland loss for 100 years due to subsidence, oil and gas withdrawal, sediment starvation due to river diversion, and sea-level rise. The USGS is studying methane production in marshes with varying salinities to quantify the methane emissions as a function of marsh type. The results of these measurements will be used to project the local and world-wide effects of sea-level rise and wetland salinization on methane emissions.



The 1980 eruption of Mount St. Helens in Washington State was a natural source of atmospheric contaminants that included

particulates, carbon dioxide, forms of gaseous sulfur, and trace elements.

Oil and petroleum spills

Maritime oil spills from freighters such as the *Torrey Canyon* and the *Amoco Cadiz* in the 1960's and 1970's focused the world's attention on petroleum pollution at sea and the devastating effects on coastal ecosystems. In March 1989, the United States was awakened to the enormity of the environmental impact and cost of such a calamity when the *Exxon Valdez* spewed 11 million gallons of crude oil into Prince William Sound, Alaska. Although the spill was approximately 30 times smaller than the *Amoco Cadiz*, it affected more than a thousand miles of coastline in a highly productive cold-water ecosystem and killed more wildlife than any previous spill. The death

toll of sea birds alone has been estimated to be 100,000 to 300,000.

As the Alaskan oil spill spread, the more volatile components were lost to the atmosphere. Oil was emulsified with sea water, where it continued to degrade or weather and was deposited on shorelines and intertidal zones. In the aquatic and terrestrial environments, naturally occurring microorganisms further degraded the petroleum. Along portions of the Alaskan coastline, "bioremediation" was used to speed up the natural bacterial oil degradation by the addition of nutrients and apparently served as a safe cleanup alternative. Some of the coastal ecosystems appear to be recovering rapidly.



Oil from the *Exxon Valdez* spill of March 1989 coats rocks in the intertidal zone of a beach on Green Island, Prince William

Sound, Alaska. (Reproduced with permission from the Alaska Department of Environmental Conservation, Juneau, Alaska.)

However, the true, long-term effects will undoubtedly be studied and debated for years.

An oil spill the magnitude of the *Exxon Valdez* occurs about once a year somewhere in the world, and spills of 1 million gallons occur monthly. For most Americans, however, petroleum spills are as close as their neighborhood gas station. Petroleum-contaminated soils are common throughout the United States, with spills or leaks occurring at petroleum refineries, fuel transportation or storage facilities, petrochemical plants, underground storage tanks at gas stations, and at homes with tanks of heating

fuel. These spills present a human health hazard because of potential contamination of drinking water or direct exposure to toxic and carcinogenic compounds. The risks associated with petroleum-contaminated soils may be great and immediate, or they may be minimal, depending upon the nature of the contaminant and the geologic and hydrologic properties of the site. Understanding the physical, chemical, and biological processes affecting hydrocarbons in soil and ground water is the key to appropriate and cost-effective remediation of petroleum contamination.

Point sources of contamination—Industrial and natural

Point-source pollution comes from a single source located in a small area such as a factory, power plant, or natural spring. There are many types of point-source pollution that degrade the quality of water, air, and soils. Examples include: (1) emissions of particulates and acidic gases into the atmosphere from active volcanoes, (2) metalliferous springs whose waters have interacted with unmined mineral deposits, (3) natural oil seeps, and (4) acid-mine drainage from mine and mill tailings. If pollutants are released underground, they can contaminate both ground water and the rock aquifers through which the ground water flows.

Air pollution can arise from activities such as power generation, mineral smelting, or industrial processing. Solid particles (particulates) generated by these sources can degrade air quality and visibility, and gases released from these sources (such as sulfur dioxide and various nitrogen gases) can react with atmospheric water to generate rain that is acidic or that has other chemically hazardous qualities.

Soil pollution can result from both air- and water-based pollution. For example, high

concentrations of heavy metals can be found in soils near smelters and in soils through which metal-bearing surface waters or ground waters have flowed.

To effectively clean up sites that have been affected by point-source pollution, it is necessary to understand the geochemical processes that control how the pollutants interact with the environment.

The following two USGS activities involving both general research and specific site studies help address the geochemical behavior of natural and human (anthropogenic) point-source contaminants.

In Hawaii, USGS scientists are examining the origin of natural, volcano-related, acidic aerosols in the atmosphere, which can cause respiratory problems among island inhabitants. Chemical and isotopic data on the aerosols show whether they resulted from the interactions of molten lava from the Kilauea Volcano with sea water or from the reaction of sulfur dioxide of volcanic origin with moisture in the atmosphere. By understanding the origin of the aerosols, health officials can recommend measures to help humans avoid contact with the aerosols.



What is wrong with this picture? The sun is shining, and an irrigation ditch is bringing life-giving water to crops near the Arkansas River in Colorado. However, the ditch is also receiving uranium- and salt-laden runoff and seepage from nearby irrigated fields.

Agricultural practices improper for a climate or soil may exaggerate normal weathering processes, and they can contaminate ground and surface waters and soils with dissolved salts and harmful trace elements such as uranium, selenium, and arsenic.

Another study showed that springs in areas of uranium-rich bedrock can be local-point sources of dissolved uranium. The uranium is dissolved during normal weathering of uranium-rich rocks and can be reconcentrated onto organic matter as the springs emerge in organic-rich soils or wetlands. The following is an example of one such uranium-bearing spring that enters a wetland in the Colorado Rocky Mountains. The natural spring waters that help sustain this wetland contain 30 to 80 ppb uranium compared to a regional background value of less than 5 ppb. The concentration of dissolved

uranium by peat is very efficient and produces haloes (peat regions that are high in uranium) in the immediate vicinity of the emergent source springs. Dried samples of peat collected near the spring pools contain as much as 3,000 ppm uranium, which represents up to a 100,000-fold concentration. The figure on page 29 illustrates the distribution of uranium in peat near one of the spring pools.

This direct observation of the extraction of uranium by peat provides another example of how wetlands can improve water quality through their metal-sorption capabilities.

Nonpoint sources of contamination—Agricultural and natural

Nonpoint-source contamination has no single, clearly defined source area and can result from both natural and human-induced processes. The most commonly studied are those either introduced or exacerbated by human activities. Agriculture is an important nonpoint source of contamination. This is a result of two generalized activities: (1) leaching of contaminants that man has added to the soil or the crops, such as organic herbicides or pesticides and nitrates or phosphates from fertilizers; and (2) leaching of naturally occurring pollutants in the soil, chiefly as the result of irrigation, which are then concentrated to abundances incompatible with plant or animal life.

The role of the USGS in the study of nonpoint-source pollution studies is focused on its ability to understand the chemical and physical processes controlling the pollutants in the environment. The definition of baselines in both agricultural and native soils and parent material has helped define what the pollution source is, how large the source is, the associated elements, and what the controlling processes are. With the knowledge of source and controls, remediation steps can be effectively planned and implemented with minimal impact on human health.

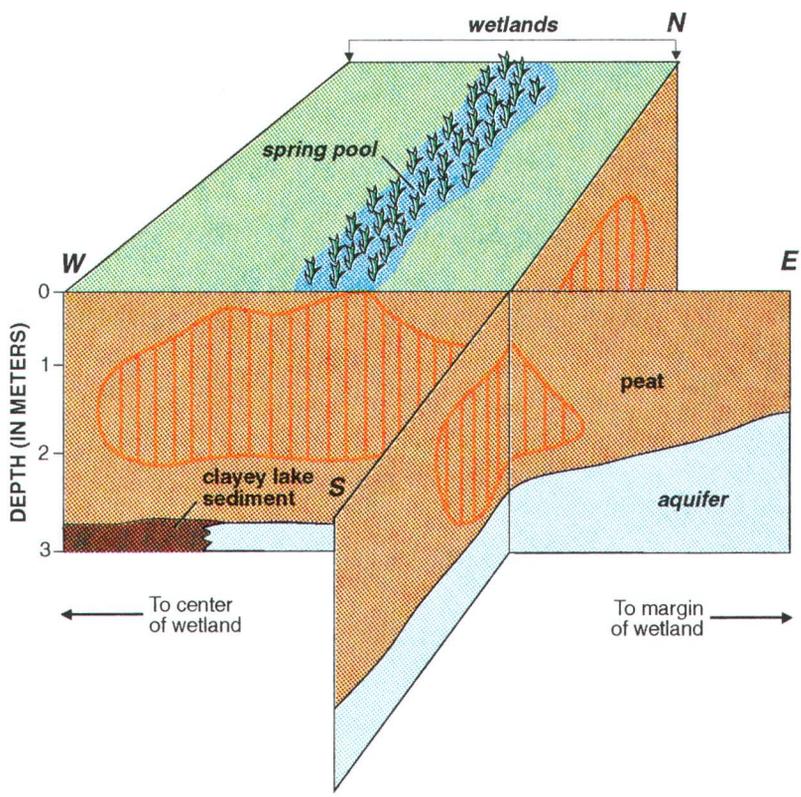
Uranium from marine deposits

Marine shales and sandstones underlie large parts of the Western United States. Much of the uranium in these rocks is loosely bound and can weather under conditions typical of the semiarid West. Irrigation can increase the natural loss of the uranium.

Runoff from irrigation may directly re-enter irrigation ditches for reuse. Local ponding of runoff waters or creation of waterlogged soils can also bring uranium and other elements to the surface, where they are concentrated by evaporation. Soils thus contaminated may be rendered unfit for cultivation. Additionally, uranium and other elements concentrated at the surface may be

removed by rainfall runoff and carried downstream, thus contaminating waters far beyond the irrigated fields.

Irrigation-return waters, regardless of the paths they have followed, may drain into their originating rivers via natural or artificial flow paths. Further downstream they may be taken out again and again for irrigation. When these waters become unfit for use on fields, they may be stored in permanent reservoirs and become more saline through further evaporation. These reservoirs may reach high levels of toxicity for animal or plant life. Towns and individuals may get their drinking water from aquifers that have been recharged, in part, by irrigation-return waters.



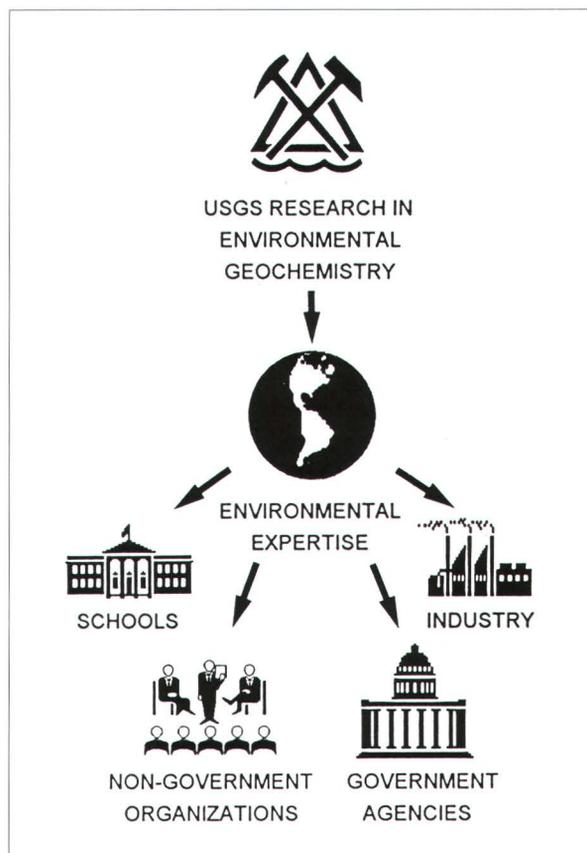
Spring water enters the peat from the underlying sandy horizon shown in blue. The ruled pattern indicates the depth distribution of peat containing more than 500 ppm uranium that was encountered in two perpendicular sampling traverses. Note that the most uraniumiferous peat is apparently confined to within a few meters of the spring pool.

New areas of concern—A look to the future

The first Earth Summit in Rio de Janeiro, Brazil, in 1992 identified *global climate change*, the *sustainable management of land and resources*, and *biodiversity* as the major international environmental issues of this decade. Both developed and developing countries perceived these issues to be important to the long-term environmental health of the planet.

We have seen through the principles and examples described in this publication that geochemistry has become an important tool in environmental studies and in understanding the processes that affect our chemical environment. Geochemical processes are involved in climate-change concerns, land-use practices, and the health of organisms, ecosystems, and the entire biosphere.

As the figure shows, the work of the USGS, whether it be geologic studies, water-resources investigations, or national-mapping activities, helps create a body of expertise and earth-science information that is used by the public and Government agencies.



USGS activities in geologic studies, water-resources investigations, and national-mapping services all contribute to a body of knowledge and information used by the public and other Government agencies. By providing material such as interpretive maps, predictive models, and risk assessments, the USGS actively serves the environmental information needs of various educational institutions; non-government organizations; local, State, and Federal agencies; and industrial consortia.

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Information Sources

(This list is by no means complete or all inclusive—there are many other government and nongovernment organizations that provide valuable data, interpretations, and trend analyses in the field of environmental geochemistry.)

- American Chemical Society**, Washington, D.C.—Publishes popular as well as scientific treatises on several different perspectives related to the environment. (800-333-9511)
- American Society for Surface Mining and Reclamation**, Princeton, West Virginia—Publishes treatises, newsletters, and general information booklets on topics related to surface mining and land reclamation. (304-425-8332)
- Council for Agricultural Science and Technology**, Ames, Iowa—CAST is a nonprofit organization composed of 29 member scientific societies that provides scientific information on key national issues in food and agriculture to policy makers, the news media, and the public. It is a non-advocacy, educational organization. (515-292-2125)
- Council on Environmental Quality** (Executive Office of the President), Washington, D.C.—Source of trends and general statistics on various topics of national interest including water; wetlands and wildlife; mining, minerals, and energy; land resources; population; and environmental risks and hazards. (202-395-5750)
- Electric Power Research Institute**, Palo Alto, California—EPRI operates under the voluntary sponsorship of the Nation's electric utility industry for the purpose of expanding electric energy research and development. Environmental considerations are a major area of research funding. (415-855-2150)
- Office of Surface Mining, Reclamation, and Enforcement** (Department of the Interior), Washington, D.C.—Publishes guidebooks, holds classes, and serves as an information source for surface-mine reclamation, regulation, and remediation. (202-208-2553)
- Society for Environmental Geochemistry and Health**, University of Missouri-Rolla, Rolla, Missouri—Publishes reports on diverse topics related to environmental geochemistry including naturally occurring geochemical hazards, risk assessment, drinking-water quality, land reclamation, recycling, and human health effects. (314-341-4862)
- Soil Science Society of America**, Madison, Wisconsin—Publishes books, journals, and popular treatises on environmental geochemical issues including macro- and micro-nutrients, analytical methods, pesticides and herbicides, metal mobility, land reclamation and remediation, geographical information systems (GIS), and land-use planning. (608-273-8080)
- Society of Wetland Scientists**, Wilmington, North Carolina—Professional society and the source of information on wetlands research, conservation, and legislation. (913-343-1221)
- U.S. Bureau of Mines Research Center**, Denver, Colorado—Provides information on research in mine safety, reclamation, and environmental science as well as trends and analyses concerning mining productivity. (800-238-4274)
- U.S. Environmental Protection Agency**, Center for Environmental Research Information, Cincinnati, Ohio—Publishes and distributes both technical and popular publications on a variety of environmental topics that focus on human health and risk assessments. (513-569-7562)
- U.S. Geological Survey Earth Science Information Center**—Provides information, both hard-copy and digital, for all map subjects including satellite, geologic, hydrologic, land use, and aerial. A fee is usually required. (800-USA-MAPS)

Glossary

adit—A nearly horizontal entrance to a mine.

background—In environmental geochemistry, this refers to a chemical level that has not been influenced by man's activities.

baseline—In environmental geochemistry, this refers to a chemical level that is typical for an area that probably has been influenced by man's activities.

bioavailability—The ability of a chemical form of an element to be incorporated into plant or animal tissue.

Celsius (or centigrade)—Measure of temperature where 0 and 100 are the freezing and boiling points of water, respectively.

deposition—Process of depositing or settling.

EPA—U.S. Environmental Protection Agency.

FDA—Food and Drug Administration.

leach—Removal (usually by water) of the easily dissolvable part or mineral fraction.

mg/L—Milligrams per liter (equivalent to parts per million).

pH—Scale of hydrogen ion (H^+) concentrations; equals the negative log of the H^+ concentration; measure of acidity of a solution. The lower the number, the higher the acidic content.

ppb—Parts per billion (microgram per liter; microgram per kilogram); a term used to describe concentrations; a ppb has been described as a family of five in a world with a global population of five billion—which is the approximate current world population.

ppm—Parts per million (milligram per liter; microgram per gram); a term used to describe concentrations.

ppt—Parts per trillion; a term used to describe concentrations.

solution—A liquid (usually water) with its dissolved components (example, salt in water).

Superfund—Areas designated by the EPA as heavily contaminated and in need of remediation and that are part of the National Priorities List (NPL).

suspension—A liquid (usually water) with its undissolved solid components (example, fine silt in water).

toxicity—the extent, quality, or degree of being poisonous. Because of dose and exposure requirements, a substance may be toxic but not necessarily hazardous to either plant or animal health.

trace element—Elements of the Periodic Chart that usually occur in common materials (rocks, soils, plants, water) at concentrations of less than 1 percent.

USDA/ARS—U.S. Department of Agriculture, Agriculture Research Service.

USGS—U.S. Geological Survey, Department of the Interior.



Mount Spur, the farthest peak to the left, seen here 80 miles southwest of Anchorage, Alaska, is an active volcano. The volcanic ash particles that periodically rain down over this area are responsible for the very deep soils that support the tundra vegetation. Recent geochemical studies of the area that is underlain

by massive coal deposits have shown that (1) there is little regional geochemical change across the landscape, and (2) the ash contains very small concentrations of environmentally important heavy metals.

Back cover: *Industrial pollution created by an ore smelter in an otherwise pristine Arizona desert ecosystem. Scientific monitoring of point sources of contamination is a topic of study in environmental geochemistry.*

