Western Mineral and Environmental Resources Science Center—Providing Comprehensive Earth Science for Complex Societal Issues

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By David G. Frank, Alan R. Wallace, and Jill L. Schneider

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U.S. Geological Survey, Reston, Virginia: 2010

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Suggested citation:
Frank, D.G., Wallace, A.R., and Schneider, J.L., 2010, Western Mineral and Environmental Resources Science Center—providing comprehensive earth science for complex societal issues: U.S. Geological Survey Circular 1363, 32 p.

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Western Mineral and Environmental Resources Science Center—Providing Comprehensive Earth Science for Complex Societal Issues

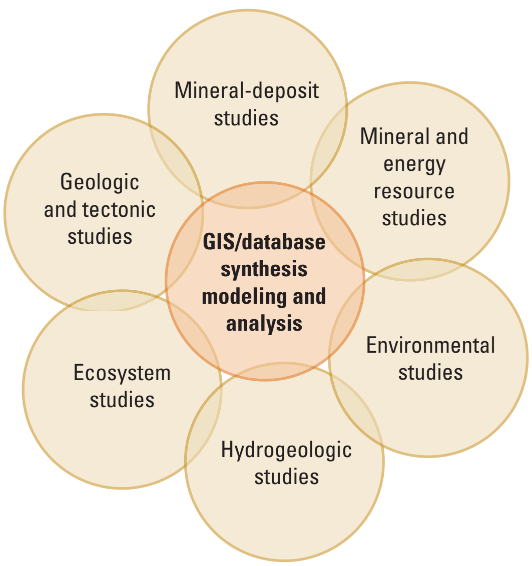
By David G. Frank, Alan R. Wallace, and Jill L. Schneider

Introduction

Minerals in the environment and products manufactured from mineral materials are all around us and we use and come into contact with them every day. They impact our way of life and the health of all that lives. Minerals are critical to the Nation's economy and knowing where future mineral resources will come from is important for sustaining the Nation's economy and national security.

The U.S. Geological Survey (USGS) Mineral Resources Program (MRP) provides scientific information for objective resource assessments and unbiased research results on mineral resource potential, production and consumption statistics, as well as environmental consequences of mining. The MRP conducts this research to provide information needed for land planners and decisionmakers about where mineral commodities are known and suspected in the earth's crust and about the environmental consequences of extracting those commodities. As part of the MRP scientists of the Western Mineral and Environmental Resources Science Center (WMERSC or "Center" herein) coordinate the development of national, geologic, geochemical, geophysical, and mineral-resource databases and the migration of existing databases to standard models and formats that are available to both internal and external users. The unique expertise developed by Center scientists over many decades in response to mineral-resource-related issues is now in great demand to support applications such as public health research and remediation of environmental hazards that result from mining and mining-related activities.

WMERSC staff use geographic information systems (GIS) to synthesize and analyze data from a wide variety of scientific disciplines and, ultimately, to deliver results to collaborators and cooperators.



Western Mineral and Environmental Resources Science Center

Results of WMERSC research provide timely and unbiased analyses of minerals and inorganic materials to (1) improve stewardship of public lands and resources; (2) support national and international economic and security policies; (3) sustain prosperity and improve our quality of life; and (4) protect and improve public health, safety, and environmental quality. The MRP supports approximately 40 USGS research specialists who utilize cooperative agreements with universities, industry, and other governmental agencies to support their collaborative research and information exchange.

Scientists of the WMERSC study how and where non-fuel mineral resources form and are concentrated in the earth's crust, where mineral resources might be found in the future, and how mineral materials interact with the environment to affect human and ecosystem health.

Natural systems (ecosystems) are complex—our understanding of how ecosystems operate requires collecting and synthesizing large amounts of geologic, geochemical, biologic, hydrologic, and meteorological information. Scientists in the Center strive to understand the interplay of various processes and how they affect the structure, composition, and health of ecosystems. Such understanding, which is then summarized in publicly available reports, is used to address and solve a wide variety of issues that are important to society and the economy.

WMERSC scientists have extensive national and international experience in these scientific specialties and capabilities—they have collaborated with many Federal, State, and local agencies; with various private sector organizations; as well as with foreign countries and organizations. Nearly every scientific and societal challenge requires a different combination of scientific skills and capabilities. With their breadth of scientific specialties and capabilities, the scientists of the WMERSC can provide scientifically sound approaches to a wide range of societal challenges and issues. The following sections describe examples of important issues that have been addressed by scientists in the Center, the methods employed, and the relevant conclusions. New directions are inevitable as societal needs change over time.

Scientists of the WMERSC have a diverse set of skills and capabilities and are proficient in the collection and integration of new and existing data and in the use of those data to arrive at scientifically sound conclusions. Scientific specialties and capabilities include, but they are not limited to:

Economic geology and petrology—understanding ore-forming processes and the controls that affect the distribution of ore deposits to develop descriptive, genetic, as well as grade and tonnage mineral-deposit models

Geochemistry and biogeochemistry—determining distributions of elements, particularly metals and metalloids, in rock, water, soil, and vegetation and defining the processes that affect their concentration, transport, and fate in natural systems

Geophysics—determining and interpreting gravity, magnetic, electromagnetic, and seismic signatures of geologic settings to identify subsurface features and processes

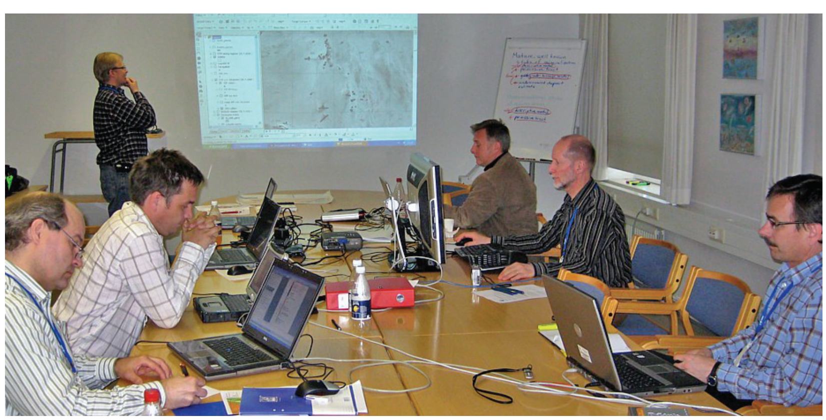
Remote sensing—determining surface geology, subsurface geologic structure, hydrology, vegetation and other land cover for large, inaccessible areas

Integrated geologic analysis—determining geologic, structural, and tectonic history; hydrologic setting of geologically complex areas; as well as ongoing natural processes that affect these areas

Mineral-resource assessments—conducting research on new methods to evaluate resource potential, analyzing economics of mineral commodities, understanding the geologic history and characteristics of an area, defining what processes formed the mineral deposits, and identifying keys to predicting undiscovered deposits

Integrated ecosystem analysis—determining the relationships between geologic environments and habitat conditions and health, including human health, particularly in mineralized settings

Geographic information system skills—compiling, numerically modeling, and analyzing complex geoscience data



A panel of USGS and other geoscientists collaborate on a mineral-resource assessment for platinum-group-metal deposits.

Mercury

Silver

Copper

Many different types of mineral deposits form as a result of igneous, sedimentary, metamorphic, biologic, and tectonic processes that occur in a particular region. Even similar deposits within a region can show subtle, but important, variations in their evolution, modification, and occurrence. The more knowledge we have about these factors, the better equipped we are to discover new deposits to meet growing demands for commodities and to develop improved methods for more efficient extraction with reduced environmental impact. To reliably develop new and improve existing mineral-deposit models, many different aspects of known deposits are thoroughly examined—these include geologic structure and history, tectonic framework and history, as well as economic factors. In addition, geochemical, geophysical, isotopic, fluid-inclusion, and remote-sensing data are collected. The diverse information and data are integrated to develop the spatial-temporal framework and genetic model for a specific mineral deposit and also to refine the generic model for that deposit type.

Copper-Silver Deposits of the Revett Formation, Montana and Idaho

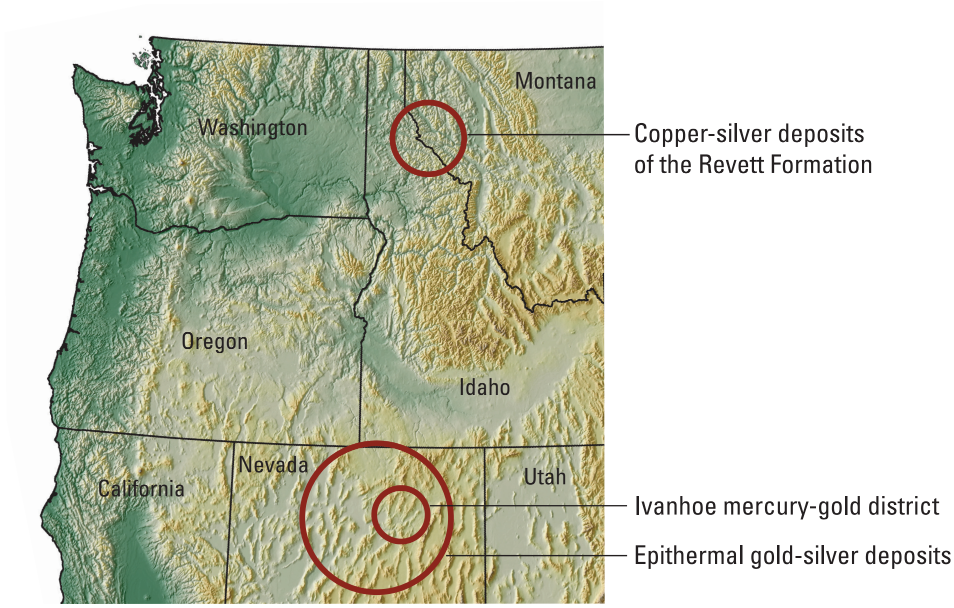
At the request of the U.S. Forest Service (USFS), WMERSC scientists compiled the regional stratigraphy and mineralogy of the Revett Formation and performed a mineral-resource assessment of Revett-type copper-silver deposits. An analysis of the data helped to define the spatial distribution of copper-silver mineralization in the Revett Formation—this analysis revealed that approximately 556 square miles of mostly USFS administered lands are favorable for undiscovered copper-silver deposits. These interpretations will serve as a useful guide for future mineral-resource exploration and will allow the USFS to incorporate geoscience information into its land-management process and land-use decisions in which mineral-resource development must be weighed against other uses such as habitat preservation and recreation. For a more detailed discussion about the copper-silver deposits of the Revett Formation, see Frost and Zientek (2006).

Geology of the Ivanhoe Mercury-Gold District, Northern Nevada

Ongoing research by WMERSC scientists into the origins of mercury-gold deposits in northern Nevada has shown that, approximately 15 million years ago, a combination of volcanism, extensional faulting, and lacustrine sedimentation resulted in the formation of near-surface mineralization, such as the mercury-gold deposits of the Ivanhoe district. Since the time they were deposited,

USGS photograph by Jeffrey Mauk

USGS scientists recently completed an assessment of copper-silver deposits in the Revett Formation in northwestern Montana and northern Idaho. This photograph shows an outcrop of Revett Formation quartzite beds in the Coeur d'Alene mining district of northern Idaho.

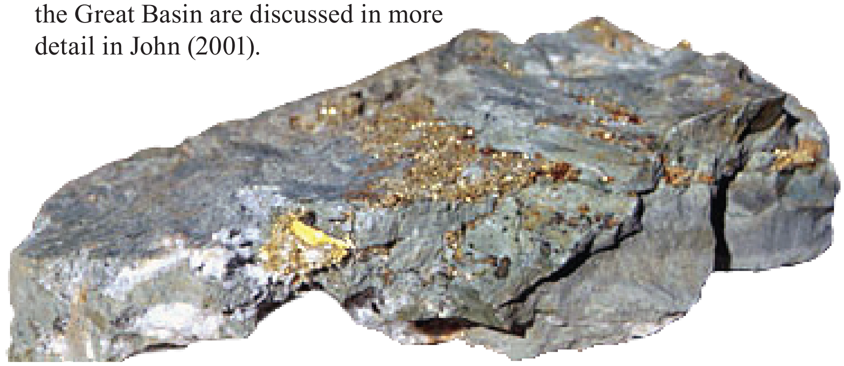


Circles show approximate locations and boundaries.

erosion has exposed varying levels of the underlying mineralized systems. The mineral-deposit model proposed by WMERSC scientists has allowed the evaluation of new potential gold bearing areas and has led to a better understanding of the mineralization in this mining district. The results of this study were also incorporated into a much broader study of long-term landscape evolution in northern Nevada, which provides insight into regional pre-, syn-, and post-mineralization in a wide variety of gold deposits in northern Nevada. For more information about the Ivanhoe mining district, see Wallace (2003).

Deposits in the Northern Great Basin, Western United States

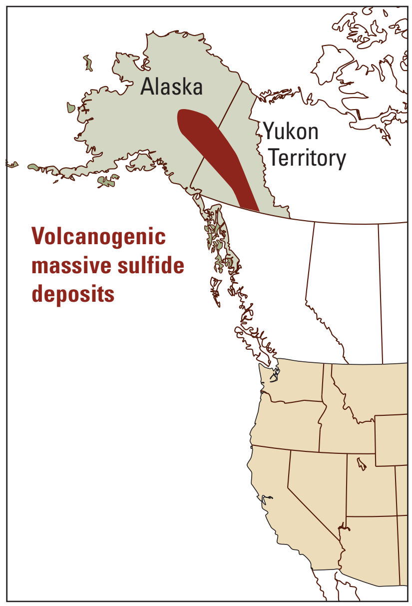
Many major epithermal gold-silver deposits, including the Comstock, Tonopah, Goldfield, and Midas deposits, were formed in the northern Great Basin of the western United States between 21 million and 4 million years ago. These deposits can be grouped into two categories, each of which is closely associated both spatially and temporally with a distinct magmatic assemblage. Andesites tend to host gold-silver deposits that are rich in base metals (copper, lead, and zinc, for example) and sulfides (pyrite and galena, for example), whereas basalt-rhyolite suites tend to host gold-silver deposits that have low base-metal and sulfide contents. Both assemblages are widespread across the Great Basin and largely reflect differences in the tectonic environments in which the magmas were generated and emplaced. Comparison of Great Basin deposit types and their magmatic settings to similar deposits in other parts of the world suggests that these relations may be common. This insight has important ramifications for mineral exploration worldwide. These epithermal gold-silver deposits of the Great Basin are discussed in more detail in John (2001).



Gold ore from Olinghouse Mine in Washoe County, Nevada.

Rocks of East-Central Alaska and Adjacent Yukon Territory

This study was initiated in response to new discoveries in Yukon, Canada, of volcanogenic massive sulfide (VMS) deposits, an important source of zinc, lead, copper, gold, and silver. The work was part of the Ancient Pacific Margin National Mapping Program, a five-year cooperative geoscience agreement between Canadian provincial and national geological surveys and the USGS. Scientists of the WMERSC investigated the Paleozoic evolution of, and the genesis and distribution of mineral deposits within, a 500-km-long belt of rocks extending from east-central Alaska to southern British Columbia. Detailed examinations to determine the age, composition, and structure of these rocks were performed. Results of this study show that highly elevated levels of certain trace elements in metamorphosed rhyolites, whose major-element compositions have been altered during metamorphism, are an important prospecting tool for volcanic-hosted sulfide deposits. This new understanding of how VMS deposits formed can be used to predict where similar deposits may be found in other areas with comparable geologic and tectonic characteristics. For more information on volcanogenic massive sulfide deposits in the Yukon Territory, see Dusel-Bacon and others (2006).



Approximate location of where VMS deposits in Alaska and Yukon Territory might be present shown in red.

USGS photo: Alan R. Wallace

The Coeur Rochester Mine in the Humboldt River Basin is the largest operating silver mine in the conterminous United States. The silver-rich ores are being mined with open-pit methods, which is a common technique for mining silver and gold in the region. In 2003, mining in Nevada produced $50 million of silver (56 percent of U.S. consumption) and $2.7 billion of gold (82 percent of U.S. production).

Mineral Assessments and Energy Resource Investigations

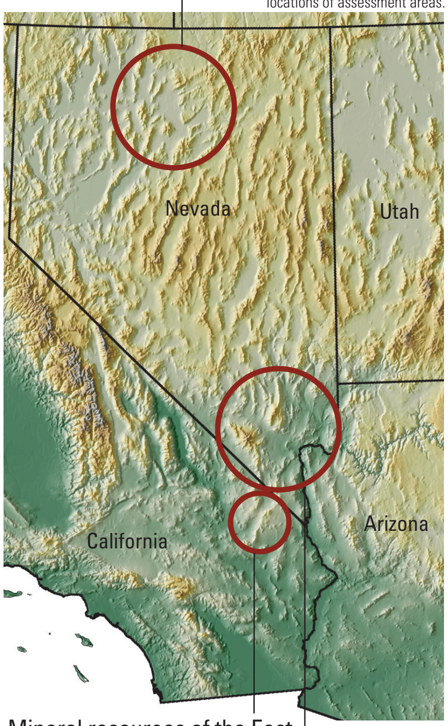
Ensuring a secure supply of mineral commodities depends on knowing the location, quality, and quantity of those resources. The WMERSC conducts studies that produce scientifically accurate and reproducible mineral-resource assessments. In a targeted area of known mineralization, research studies are conducted to understand the geologic history and characteristics of that area, define which processes formed the mineral deposits, and identify the parameters that indicate the presence of those deposits. Center scientists can then use this data to evaluate the quality and quantity of potential mineral deposits in similar geologic terrains. Assessments at a variety of scales provide valuable information to a range of users, including Federal, State, and local land-use managers.

Mineral-Resource Assessments in Clark and Nye Counties, Nevada

The U.S. Bureau of Land Management (BLM) tasked WMERSC scientists with providing information for use in BLM's long-term land-use planning process in southern Nevada. Existing geoscience data were compiled about the target areas, including geology, geophysics, geochemistry, and mineral-deposit information, and field studies of selected areas and mineral occurrences were conducted to determine their geologic setting and metallogenic characteristics. Numerous areas were delineated where the presence of undiscovered mineral resources is likely. The assessment was conducted in partnership with the University of Nevada, Las Vegas, and the Nevada Bureau of Mines and Geology, a part of the University of Nevada, Reno. A substantial part of the funding for this activity was provided to these two partners through cooperative agreements with the USGS. To read the complete mineral-resource assessment, see Ludington (2006).

East Mojave National Scenic Area, California

By evaluating model-based criteria, USGS scientists concluded that much of the East Mojave National Scenic Area (East Mojave study area) may contain concealed mineral deposits that formed at or near the earth's surface. While the presence of any mineralization in covered areas is yet unknown, igneous rocks in the East Mojave study area bear striking physical and chemical similarities to those in adjacent mountain ranges that do contain mineral deposits. Discovery of near-surface deposits is difficult because they are usually covered by a thin cap of gravels and they do not respond to standard geophysical methods of detection, particularly at the coarse spacing of the data-collection points available for evaluation. Nevertheless, significant concentrations of many metals may remain to be discovered in various parts of the East Mojave study area—the igneous rocks there are indicative of a metallogenic environment that may have given rise to mineral-deposit types not yet recognized by the exploration community.



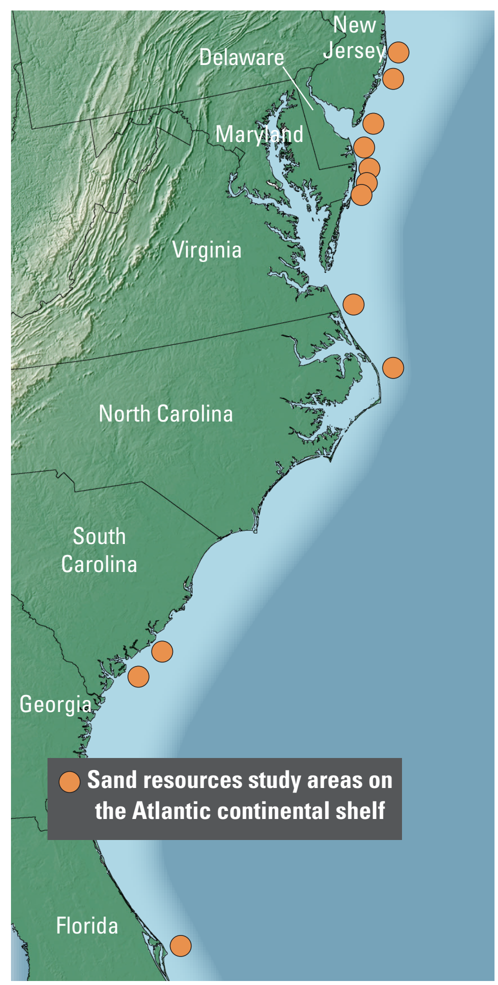
In preparation for the East Mojave study, the known mineral resources of the eight areas formerly recommended as Wilderness Study Areas by BLM, as well as of all others recommended for wilderness designation within the California Desert Conservation Area, were examined by the U.S. Geological Survey and the U.S. Bureau of Mines, and a Mineral Summary was prepared as background data for the California Desert Protection Act of 1987. These studies were preliminary and recommended additional investigations before any land-use decisions were made, particularly where substantial mineral resources were identified. To read the complete report, see Theodore (2007).

Humboldt River Basin, Northern Nevada

The Humboldt River Basin in northern Nevada has been one of the world's most important sources of gold, silver, copper, mercury, and tungsten. In 2003 Nevada was the third largest producer of gold in the world and the largest producer of silver in the United States. Nevada covers approximately 16,600 square miles (43,000 km^2) of arid to semiarid land, much of which is publicly owned and administered by the BLM. Minerals-related activities, including mineral exploration, are among the multiple uses of these lands. Scientists from the WMERSC completed and published a major assessment of metallic-mineral resources in the Humboldt River Basin and adjacent areas of northern Nevada. The report identifies large areas of the region that may contain undiscovered metallic mineral deposits and that may be suitable as sites for future mining activities. The results of the assessment are portrayed on three maps of the region, along with extensive accompanying descriptions (see Wallace and others, 2004). These results can be integrated into BLM's long-term land-use planning for the Humboldt River Basin.

Marine Sand Resources Along the Atlantic Coast

Governments with jurisdictions that include coastal areas and beaches face challenges in both trying to safeguard these environments from erosion, as well as to mitigate the effects of such erosion. In these efforts, marine sand is used to protect and rebuild areas, harbors, and coastal roads. The U.S. Army Corps of Engineers and other Federal agencies have crucial roles in helping local governments deal with coastal erosion—they need to know how much usable marine-sand resources may be present offshore and what might be available to supply coastal states and local governments. By studying cape- and ridge-associated marine-sand deposits, which constitute the best sources for high-quality sand on the U.S. Atlantic Coast, WMERSC scientists used computer simulation to identify three areas between eastern Long Island of New York and southern New Jersey where these deposits are predicted to contain a total of 3.9 billion cubic meters of marine-sand resources. This is the first time this particular approach has been used, but already several new areas have been outlined on the other parts of the East Coast of the United States for study. The USGS Marine Aggregates Resources and Processes Project supported this modeling research. For more details on modeling these marine-sand deposits, see Bliss and others (2009; 2010).



Areas above the Arctic circle where oil and gas might be found.

Assessment of Oil and Gas in the Arctic

To improve the understanding of the petroleum resources in this area, the USGS is undertaking a multi-year research effort, termed the Circum-Arctic Resource Appraisal (CARA), to produce a comprehensive, unbiased, scientifically determined estimate of undiscovered petroleum resources in the high northern latitudes. This research effort is being conducted in collaboration with several U.S. and international entities. When completed, the results from the CARA will provide the first publicly available petroleum resource estimate of the area north of the Arctic Circle in its entirety. Scientists from the WMERSC assisted USGS Energy Resources Program scientists in completing an assessment of undiscovered conventional oil and gas resources in the Arctic region (all area north of the Arctic Circle line of latitude). Using a geology-based probabilistic methodology, the scientists estimated the occurrence of undiscovered oil and gas in 33 geologic provinces thought to be prospective for petroleum. The sum of the mean estimates for each province indicates that 90 billion barrels of oil, 1,669 trillion cubic feet of natural gas, and 44 billion barrels of natural gas liquids may remain to be found in the Arctic, of which approximately 84 percent is expected to occur in offshore areas. To read this assessment, see Gautier and others (2009).

Preliminary Non-Fuel Mineral-Resource Assessment of Afghanistan

Between 2005 and 2007, the U.S. Agency for International Development (USAID) funded the USGS to assess Afghanistan's non-fuel mineral resources. Mineral-resource assessments provide government decisionmakers, potential private investors and mineral-exploration companies with information on where undiscovered mineral resources may be located, what kinds of resources are likely to occur, and how much metal may exist in them. This information makes wise management of natural resources possible. The USGS compiled all published and unpublished reports, maps, and satellite imagery of the country into a geographic information system (GIS) software package and used the data to compile a preliminary assessment. Twenty mineralized areas were identified that merit further study. The assessment was conducted in cooperation with the Afghan Geological Survey, and USGS scientists provided training to their scientists in modern methods of resource assessments. This preliminary assessment sets the stage for more targeted resource assessments that are designed to increase the knowledge base and accuracy of the potential mineral-resource reserves in Afghanistan. These refined, more detailed assessments may assist USAID in fostering economic development in various parts of Afghanistan. This mineral-resource assessment of Afghanistan is available from the U.S. Geological Survey website (Peters and others, 2007).

Using a preliminary geologic map, WMERSC staff work with collaborators to interpret information in the field.

Geologic, Tectonic, and Hydrologic Studies

A strong understanding of the geologic evolution of a region provides fundamental information on the resources found in that area. This understanding comes from integrating geologic, stratigraphic, structural, hydrologic, and geophysical studies. In addition to mineral deposits, water is a critical resource in the western United States, where the population is growing rapidly and much of the climate is semi-arid. Integrated studies provide essential scientific data and interpretations that can be used by public and private entities to find, develop, manage, and preserve important water resources. These studies are also valuable for mineral-resource exploration and assessments, as well as for evaluating and mitigating various geologic hazards.

Paleogeographic Evolution of Northeastern Nevada

The landscape of northeastern Nevada has evolved over the past 20 million years as a result of many tectonic, sedimentary, geomorphic, and igneous processes. Geologic mapping and detailed geochronologic studies by WMERSC scientists were merged to unravel the area's geologic history and to show how those various processes led not only to the erosion and concealment of older mineral deposits, such as Carlin-type gold and porphyry copper-molybdenum-gold deposits, but also to the formation of younger hot-spring (epithermal) gold-silver-mercury deposits. The results, utilized by industry and USGS scientists, also provided important information on Tertiary aquifers in the region and showed how different lithologies and faulting control the flow of groundwater used for agriculture and mining. The results of this study are described in detail in Wallace and others (2008).

Evolution of the Rio Grande Rift, Southern Colorado

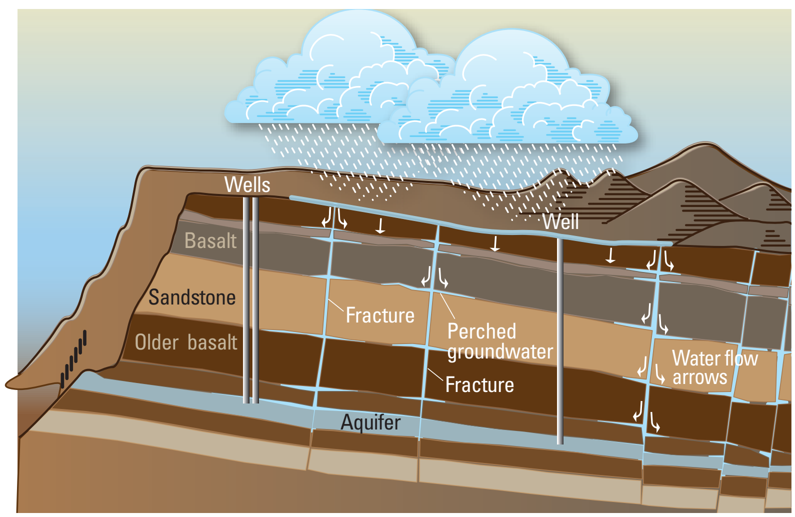
The Rio Grande Rift is a complex zone of crustal extension that extends north from the southern New Mexico border to northern Colorado. Its evolution has influenced the distribution of various mineral deposits and groundwater resources, and continued extension has produced active faulting and seismic hazards in some parts of the San Luis Basin. Mapping, geochronology, and structural analyses were conducted along the southeastern margin of the San Luis Basin in southern Colorado to better understand these resources and hazards within their geologic framework. As a result of this work, the relative ages of the mineral deposits were determined (the gold deposits are older than the fluorite deposits), and the documented lithologic and structural partitioning of the groundwater resources provided important information for agricultural uses in the area. Because faulting migrated westward through time, many of the active faults and associated seismic hazard areas extend several kilometers into the basin from the range front. The results of this study are available in Wallace (2004).

Water Resources of Aquifer Systems in Adjacent Areas of Nevada and Utah

Water is one of the most important commodities in the Great Basin, and it rarely is located in heavily populated areas where it is needed most. In response to concerns about water availability and limited hydrogeologic information, Federal legislation (Section 301(e) of the Lincoln County Conservation, Recreation, and Development Act of 2004: PL 108-424) was enacted in December 2004 that directs the Secretary of the Interior, through the U.S. Geological Survey, the Desert Research Institute (DRI), and a designee from the State of Utah, to conduct a water-resources study of the basin-fill and carbonate-rock aquifers in White Pine County, Nevada, and smaller areas of adjacent counties in Nevada and Utah. The primary objectives of the Basin and Range carbonate-rock aquifer system (BARCAS) study were to evaluate: (1) the extent, thickness, and hydrologic properties of aquifers, (2) the volume and quality of water stored in aquifers, (3) subsurface geologic structures controlling groundwater flow, (4) groundwater flow directions and gradients, and (5) distributions and rates of recharge and groundwater discharge. Geologic, hydrologic, and geochemical information are integrated to determine basin and regional groundwater budgets. The resulting report was prepared in cooperation with the BLM. At the request of the NPS, new studies are focusing on similar aquifers in and around Great Basin National Park, Nevada. For more information about the Great Basin aquifer systems, see Welch and others (2007).

Mapping Water Seepage Down Penetrative Fractures, Southwestern Colorado Plateau

Some aquifers of the southwestern Colorado Plateau are deeply buried and overlain by several impermeable lithologic units. Hence, recharge to these aquifers is most likely by seepage down penetrative fracture systems. The purpose of this integrated study with the National Park Service was to develop a method for mapping the probable locations of these penetrative fractures by correlating gravity and aeromagnetic anomalies with surficial fracture data and satellite imagery. The resultant database catalogs the estimated recharge locations, and recent studies identify a sub-set of possible penetrative fractures and define in detail the deep structure of the southwestern Colorado Plateau. This new methodology correctly identified known deep-fracture systems and many new ones, but it does not give any indication as to whether the fractures are open or closed—in other words, whether the fracture is capable of carrying fluids or not. Because deep fractures are important in structural definition and often control mineral-resource locations, the method has broader application in diverse tectonic and mineral-resource investigations. For more information on this study, see Gettings and others (2005).

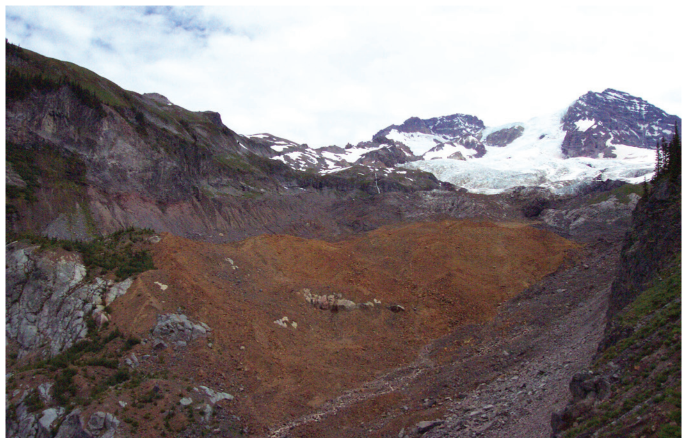


Generalized cross section of the southwestern Colorado Plateau showing how groundwater moves through the subsurface.

Hydrothermal Alteration at Mount Rainier Volcano—Implications for Debris-Flow Hazards and Mineral Deposits

This study examined the history of hydrothermal alteration at Mount Rainier during the 500,000-year episodic growth of its edifice. Whereas some alteration environments were spatially associated with dikes intruded on the volcano's east and west flanks, the most intense alteration developed within the highly permeable and porous breccias that formed near the volcano's conduit system and summit. These altered breccias are physically unstable, and the remnants of them in Rainier's Sunset Amphitheater present a continuing collapse hazard. Similar near-vent breccias at other active volcanoes may also be highly altered and present comparable hazards. The study also looked at mineral compositions and concluded that Mount Rainier's hydrothermal mineral assemblages and their areal distributions bear a strong resemblance to those developed at ore deposits formed in similar settings. Although frequent eruptions supplied sufficient fluids to hydrothermally alter the upper interior of the volcano, the magma reservoir may be too deep to foster the formation of economic mineral deposits within or at shallow depths beneath Mount Rainier. To read more about the debris-flow hazards at Mount Rainier, see John and others (2008).

Ash beds erupted during collapse of the top and north side of Mount Rainier and formation of the Osceola Mudflow at about 5,600 years before present. Light-colored beds contain abundant fragments of altered rock and hydrothermal minerals, including pyrite in gray zone near the bottom of photograph. Thin dark-gray bed near the center of exposure mostly consists of newly formed volcanic rock. The exposure is located near the head of Granite Creek on the northeast side of Mount Rainier.



View of an early 20th century rock fall that covers the toe of the Tahoma Glacier on west side of Mount Rainier. The orange color is caused by oxidation of pyrite contained in hydrothermally altered blocks in the rock fall. The rock fall originated in Sunset Amphitheater (ice-covered background) near the top of Mount Rainier.

View of Glacier Basin looking west showing 466,000-year-old dike complex intruding approximately 470,000 year old volcanic rocks. Hydrothermal alteration is generally weakly developed around the walls of the dikes despite strong discoloration. The 5,600-year-old Osceola Mudflow is exposed in the bottom of the basin.

Area of seepage from copper mining near the Elizabeth Mine in Vermont.

WMERSC scientists develop tools and techniques that are designed to (1) understand what happens when mineral deposits are weathered or mined, (2) anticipate the environmental effects of developing new mineral deposits, and (3) recognize the challenges and hazards associated with abandoned mines. These assessments provide specific information on the potential release and cycling of contaminants within the environment. Such issues are of concern to a wide range of land managers in the Federal sector, including those managers who manage our National Parks, National Forests, and Wild and Scenic Riverways, as well as to private-sector environmental groups and the general public.

Impacts of Acid-Mine Drainage on a River in Vermont

WMERSC scientists assisted the U.S. Environmental Protection Agency (EPA) in evaluating the concentration, chemical speciation, and toxicity of metals in a river downstream from the Elizabeth Mine superfund site (as defined by the EPA) in Vermont. The evaluation required multiple analytical and modeling tools and integration of results from field and laboratory studies. USGS studies have focused on understanding the chemical and hydrologic processes by which the rocks and waste piles weather to produce acid mine drainage. Cooperative efforts with the Elizabeth Mine Study Group have concentrated on assessing toxic heavy metal loads from the upper part of the watershed. To date, USGS scientists have helped train the group in water-sampling protocols, and they have also provided analytical support and assistance in data interpretation. Additional USGS efforts have also concentrated on defining the complexity of mine drainage environments at the site. Reconnaissance studies are also underway at other mines in the Vermont Copper Belt. For more information about acid-mine drainage at the Elizabeth Mine, see Balistrieri and others (2007).

Flux of Metals from Beatson Mine, Alaska

In the early 20th century, approximately 6 million metric tons of copper ore were mined from numerous deposits along the shorelines of fjords and islands in Prince William Sound (PWS), Alaska. The effect of mining-related discharge from these abandoned mines on shoreline ecosystems is unknown. To determine the magnitude of mining effects at the Beatson Mine, trace-metal concentrations and flux were measured in surface run-off from the remnant mineralized workings and waste rock. It was discovered that rainfall raised the concentrations of copper and lead in the stream draining the mine workings, but it lowered the concentrations of nickel and zinc. Over a 60-day observation period, the mass of metals transported from the mine to the PWS shoreline included 196 kg zinc, 87 kg copper, 1.9 kg lead, and 1.9 kg nickel. The results of these studies have been published (Shanks and others, 2005; Stillings and others, 2008).

Mine waste piles from the oldest phase of historic copper mining at the Elizabeth Mine, which closed in 1958. Reddish surface soils in the center of the photo are hematite-rich and mark the sites of historic copper works where ore was roasted and processed.

Tungsten Concentration in Groundwater—An Example from Fallon, Nevada

Tungsten is used in a variety of industrial, commercial, and military applications. Despite these extensive uses, information on its biological effects, toxicity, and behavior in natural environments is scarce. This study investigated the geochemistry of tungsten in groundwater aquifers near Fallon to determine the chemical form and mineralogy of tungsten in the aquifer sediments as well as to conduct experiments that allow prediction of tungsten concentrations in the aquifers. Research results show that tungsten is found associated with organic material as well as with both crystalline and non-crystalline iron minerals in the aquifer sediments. Although the data for tungsten retention by iron minerals can be used to successfully predict tungsten concentrations in groundwater, more research is needed to understand the effect of organic material on tungsten mobility in aquifers. For a more detailed discussion about tungsten in the groundwater near Fallon, see Stillings (2008).

Metal Concentrations of Floodplain Sediment in the Lower Coeur d'Alene River, Idaho

As part of the U.S. Environmental Protection Agency's (EPA) evaluation of the impacts of historical mining activities on the health of the environment and biota in the lower Coeur d'Alene River valley, WMERSC scientists conducted studies to determine the depositional rates and composition of floodplain sediments in that part of the river basin. Those studies indicated that floodplain sediment covers about three-quarters of the valley floor and is enriched in antimony, arsenic, cadmium, copper, iron, lead, manganese, mercury, and zinc. The sediment is derived mainly from mill tailings in the Coeur d'Alene mining district that, prior to 1968, were discarded directly into tributary streams. Frequent floods continue to re-mobilize sediment onto the floodplain from the river's bed, banks, alluvial terraces, and natural levees. Maps of the composition of surface sediment in the lower valley, published in collaboration with the Coeur d'Alene Tribe, were used to guide remediation work that was done to minimize health impacts to residents and visiting human and wildlife populations. For more information about metals in sediment of the Coeur d'Alene River valley, see Balistrieri and others (2002) and Bookstrom and others (2001).

WMERSC scientists developed a modified vibracore device to collect 3- to 5-m samples of the tailings-contaminated sediment from the channel of the lower Coeur d'Alene River, Idaho.

Mercury Geochemistry in the Lower Clear Creek Area, Shasta County, California

Habitat restoration in streams where gold-placer mining has occurred raises concerns about the possible release of mercury from newly disturbed dredge tailings and the subsequent availability of that mercury to biota in those streams. Clear Creek, at the northwestern edge of the Sacramento Valley, is one stream where, in addition to historic gold dredging, aggregate mining removed large quantities of gravel from its lower floodplain. This creek is an important salmon stream, and habitat restoration here is critical to repair damage from mining and to improve conditions for spawning and rearing of salmon fry. Because dredge tailings are being used to increase the area of spawning gravels and to fill gravel pits in the floodplain, it was necessary to discover if, how much, and in what form mercury might be released. The purpose of this study was to identify sources, transport, and dispersal of mercury in the lower Clear Creek area and to identify environments in which bioavailable methylmercury is produced. Analytical data acquired included total mercury and methylmercury concentrations in sediments, tailings, and water. These data were evaluated with respect to levels of mercury in biota prior to and after creek restoration. To learn more about the geochemistry of the Lower Clear Creek area, see Ashley and Rytuba (2008).

Wetlands and ponds constructed on an alluvial terrace previously mined for placer gold, lower Clear Creek, California.

Growth of Valley Fever Fungus in Soils

Valley Fever is a pulmonary disease caused by the wind-borne spores of the fungus *Coccidioidomycosis*. Although most infected individuals are asymptomatic, the disease can cause flu-like symptoms, pneumonia, and, in some cases, death. Because the fungus spends a significant part of its life cycle in the soil, its habitat was studied as part of an investigation of the interrelationship between its environment and human health. After analyzing historic climate data in the Tucson area, a model for the spread and survival of the fungus was developed. Factors affecting the establishment and growth of new *Coccidioidomycosis* colonies include wind direction and intensity; soil geology, texture, and moisture content; surface and soil temperatures; and a sufficient time interval of favorable conditions for colony survival. These results, together with supporting studies, show that both geologic and environmental soil factors control the location of infectious sites. The model explains what is known of the distribution of actual sites and provides constraints useful in mapping potentially infected sites and in mitigation work to control the disease. To read more about Valley Fever fungus in soils, see Gettings and others (2005).

A scientist collects samples from a stream. These samples will be analyzed for mineral concentrations to determine if contaminants are present.

The move towards ecosystem-based management requires an understanding of both the current relations among the physical and biogeochemical components of an ecosystem and the tools that predict how an ecosystem is expected to respond to natural and anthropogenic change. Scientists within WMERSC are able to provide this interdisciplinary and integrated science by employing three strategies. The first is to understand an area's geology, geochemistry, and the processes responsible for the formation of geologic landscapes and the re-distribution of water, sediment, and associated elements within environmental systems. The second strategy is recognizing how the distribution, cycling, and bioavailability of chemical elements are linked and how these linkages affect human and ecosystem health. And the third strategy is producing and interpreting GIS layers of information and using predictive modeling tools to aid their understanding of the spatial and temporal relations among geology, geochemistry, and biology within an ecosystem. This methodology is being used to aid Federal, State, and local land managers in their decisionmaking processes.

Effects of Rock Type on the Flora and Fauna of the Great Basin

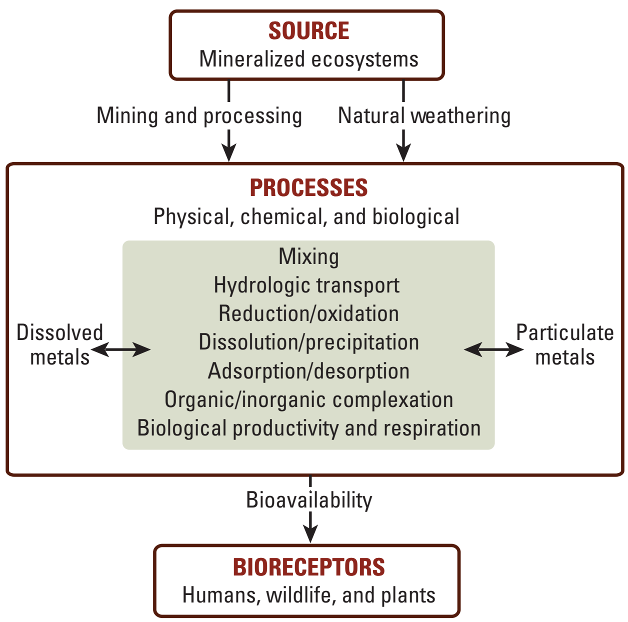
Plants and animals in the Great Basin live above a wide variety of rock types that, in places, can have a major effect on the distribution and health of biota. Scientists from WMERSC, in collaboration with biologists from the USGS, BLM, and other organizations, have begun to evaluate this rock-biota connection in an ongoing research effort. For example, they have found that a rare species of buckwheat grows only in soils developed above diatomite-bearing rocks. Thus, documenting the distribution of those rock units in the region might identify presently unknown areas that contain this and other rare buckwheats. Similarly, empirical data collected during geologic field studies showed a strong correlation between specific Miocene and Quaternary sedimentary rock units and the documented breeding sites of Burrowing Owls, which are a U.S. Fish and Wildlife species of concern. As such, the distribution of rock units in the Great Basin may serve as an indicator for the favored breeding areas of the owls. In both cases, the results of the studies provide land-use and wildlife managers with important tools for finding and evaluating rare to threatened biologic species. For more information about diatomite deposits, see Wallace, Frank, and Founie, (2006).

A scientist collects water samples from a stream to test for mercury and other contaminants.

Understanding Metal Pathways in Mineralized Ecosystems

Adverse impacts to the quality of water and sediment and to the health of humans and other biota are part of the legacy of approximately 11,000 abandoned hard-rock (mainly those containing metals) mine sites in the western United States. For ecosystems where total remediation of environmental problems is not financially or technically feasible, long-term management of potential risks is the only viable option. Successful management of such systems requires an understanding of the distribution of potentially toxic elements within the system and of the processes that transport, chemically transform, and make them available to biota. Using a combination of field, laboratory, and modeling approaches at a number of mining-impacted sites in the western United States, WMERSC scientists identified processes that influence the distribution, concentration, and bioavailability of potentially toxic elements, such as arsenic, cadmium, lead, mercury, selenium, and zinc, that have the greatest immediate and long-term impact on the environment and health of biota. This information provided the scientific foundation for making decisions, developing strategies, and assessing mitigation and remediation alternatives by local, state, and other Federal agencies charged with managing those ecosystems. For a more information about metal pathways, see Ashley and others (2002) and Balistrieri and others (2007a, b).

Metal pathways in mineralized ecosystems



Physical, chemical, and biological processes transport and biogeochemically transform elements as they are redistributed from mineralized sources (ore deposits and mine wastes) to biological organisms.

Importance of Sediment-Water Interactions in Lake Coeur d'Alene, Idaho

A century of historical mining activities in the Coeur d'Alene mining district resulted in the dispersion of metal-enriched water and sediment throughout the Coeur d'Alene River basin, including into Lake Coeur d'Alene. The stakeholders, which include the U.S. EPA, Coeur d'Alene Tribe, Idaho State agencies, and local residents, are concerned that changes in the biogeochemical conditions within the lake could result in the release of metals from the bottom sediments into the lake's water. WMERSC and other USGS scientists worked with colleagues from the University of Idaho and the Centre for Water Research at the University of Western Australia to characterize the exchange of metals between sediment and bottom water and to model the biogeochemical conditions that would enhance that exchange. The results of the studies suggested that the consequences of upstream remediation of metal sources, the increasing urbanization around the lake, and the effects of larger nutrient concentrations on metal release from bottom sediment must all be considered in a long-term management plan for the lake. For more detailed information about this research, see Balistrieri (1998).

Earth-Science Studies in Support of Public Policy Development and Land Stewardship—Idaho and Montana

The U.S. Forest Service (USFS) is working to integrate geoscience information into its land-planning decisions in the national forests of eastern Washington, northern Idaho, and western Montana, areas in the northern Rocky Mountains known for their world-class deposits of gold, copper, silver, platinum, garnet, and talc. To assist the USFS in achieving their goal, WMERSC scientists and collaborators studied the large, undeveloped copper deposits in northern Idaho and northwestern Montana and the copper-cobalt deposits in Idaho, and they looked at the relation among mineral deposits, locations of ancient faults, and the geochemistry of mined and unmined geologic terrains. The scientists prepared a geologic map, which involved reviewing and revising pertinent datasets for consistency and accessibility. These datasets included regional compilations of geologic information, locations of active mines and significant mineral deposits, and geophysical information about the distribution of rocks beneath the surface. The USFS is using this information to model different scenarios that relate land use, forest health, and landslide and wildfire hazards, and to assess the area's mineral-resource potential, which is critical for planning future mineral exploration and mining in areas managed by the USFS. Details about these studies have been published in a USGS report (Zientek and Lund, 2005; Zientek and Kropschot, 2005).

Geochemical Controls on Selenium—A Comparison of Two Wetlands

Selenium toxicity, resulting from bioaccumulation in their forage, is a serious threat to livestock and waterfowl in the western United States. Selenium may be released into surface waters during phosphate mining operations, and wetland soils and plants are known to concentrate this metal, thereby promoting its entry into the food chain. Understanding how selenium cycles through wetland systems will aid in minimizing this bioaccumulation and the consequent health risks. WMERSC scientists conducted studies in two areas: one wetland downstream from mined phosphate deposits in southeastern Idaho, and a second wetland in a nature park affected by runoff from Las Vegas, Nevada. During a five-month observation period, the Idaho wetland retained 88 percent of the selenium present in its inflowing waters, mostly due to uptake by plants and iron minerals. In contrast, the Nevada wetland retained only 24 percent of the selenium from its inflow waters, which had a much higher flow rate and less contact time with sediments and plants. As a result, land-management agencies are attempting to decrease the amount of selenium delivered to these two wetlands. The USFS in Idaho is using soil amendments and seed mixtures to immobilize selenium within the waste-rock source, and the Clark County Department of Parks and Recreation in Nevada is diverting another source of inlet water to that wetland. To read the complete abstract about this research, see Stillings and others (2007).

Potentially Toxic Trace Metals Affected by Copper Mining in Prince William Sound, Alaska

Waste from historical copper mining operations is located on the shorelines of islands and fjords in Prince William Sound (PWS), Alaska. Local residents, as well as the Chugach Alaska and Tatitlek Native Corporations, are concerned about the potential effects of this mining debris on the intertidal ecosystem, which contains filter-feeding shellfish that are locally harvested. This project investigated mining-impacted shoreline sites in PWS that were similar in ore deposit chemistry and climatic conditions, but differed in the types and quantity of tidal zone debris. By analyzing metal concentrations in clams collected from the sites, it was shown that waters of near-neutral pH and higher concentrations of dissolved organic carbon favor diverse microbial communities that accelerate the formation of iron minerals that remove trace metals from solution, thereby lowering the bioavailable metal content. Acidic waters with lower concentrations of dissolved organic carbon favor a more homogeneous microbial community and the precipitation of iron minerals that do not remove trace metals from solution. Clams in this type of environment had the highest metal concentrations of the three sites in this study. Funding for this research was provided by the USGS, the agency formerly known as Minerals Management Service (MMS), and National Oceanic and Atmospheric Administration (NOAA). To read a complete abstract about this study, see Foster and others (2005).

Information gathered in the field is entered into a geographic information system that allows scientists to synthesize and analyze the data.

GIS/Database Synthesis, Modeling, and Analysis

Geospatial technologies and analyses are important to many natural resource assessment activities. Geographic information science integrates the techniques and concepts of geographic information systems (GIS), global positioning systems (GPS), and remote sensing and involves the acquisition, transformation, management, and quantitative analysis and modeling of geographically referenced data. These methods allow for more rapid, efficient, and comprehensive data synthesis, which yields assessments that are broader in scope and more accurate and dynamic in nature. However, digital geologic maps, a major building block of minerals-related assessments, do not exist at an intermediate (1:100,000) or large scale (1:24,000) for most of the western United States, and digital maps that have been produced by other organizations cannot easily be combined due to inconsistent database structures. The Center GIS staff fulfill an ongoing need for acquisition, creation, analysis, publication and archiving of digital spatial geoscience datasets for use by staff throughout the entire Mineral Resources Program and for our other customers (including the Bureau of Land Mangement and the U.S. Forest Service, who are requiring that data be provided in an Arc/Info GIS format). In addition, the staff assists colleagues in performing minerals-related assessments by utilizing the spatial analytical capabilities inherent in GIS. The results facilitate access to our data and allow us to meet customer needs, which require results in a digital format that can be incorporated into other GIS datasets.

Spatial Data Analysis and Modeling Approaches to Natural-Resource Assessment and Regional Planning and Development

Mineral-resource applications of GIS science have included the development of rapid reconnaissance methods of assessment, an analysis of gold and silver mineralization in the Nevada Great Basin, an assessment of the Humboldt River Basin in northern Nevada, a preliminary non-fuel mineral-resource assessment of Afghanistan, an analysis of sedimentary rock-hosted gold deposits in China, and a diamond assessment in Mali and the Central African Republic. GIS science-based natural-resource analyses are becoming increasingly essential components in larger environmental/socioeconomic evaluations, where mineral-resource

Rugged notebook computers equipped with GPS and GIS software allow geoscientists to carry out real-time geologic mapping and plot the exact locations of observations and samples.

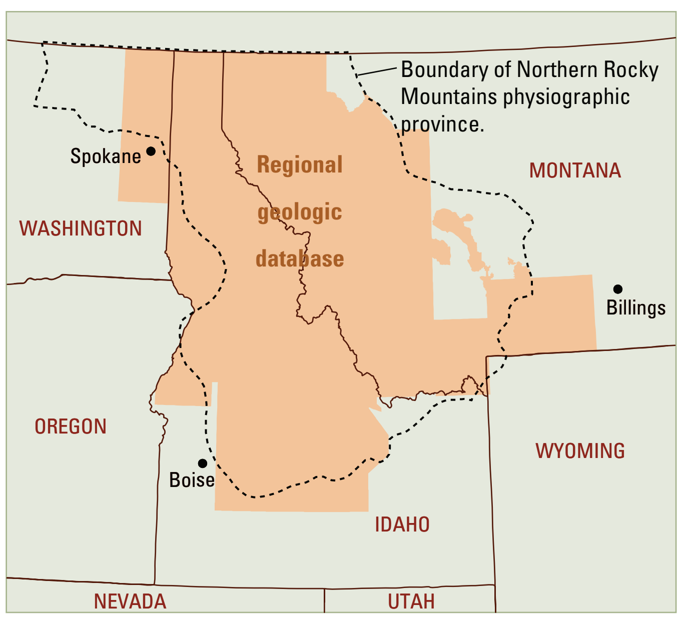
potential, particularly in the form of an assessment, contributes to regional planning and development strategies. The details and results of these various modeling approaches are discussed in various reports (see Ludington, 2006; Mihalasky, 2001; Mihalasky and Moyer, 2004; and Raines and Mihalasky, 2002).

Northern Rocky Mountains

Spatial Database for the Geology of the Northern Rocky Mountains—Idaho, Montana, and Washington

A regionally consistent and integrated geologic spatial database for the Northern Rocky Mountains physiographic province of Montana, Idaho, and eastern Washington brings together forty-three 1:100,000- to 1:250,000-scale digital geologic maps into a common database format. The database represents the original content of the published maps and provides consistent and easily used attribute content, in addition to new information-based interpretations of published reports. In particular, attribute information was added that (1) classifies igneous rocks by age, composition, and name, and (2) allows the creation of derivative maps based on mineral composition and structure of rocks. Three schemes based either on the original map units or on igneous map units, are used to classify polygons and lines in the database. The database can be queried to address an assortment of geologic questions and to produce a variety of derivative geologic maps. Digital themes derived from this database are being used by the U.S. Forest Service for planning and research purposes and by the USGS to facilitate research and conduct mineral-resource assessments. Secondary spatial databases released in the report include a georeferenced and mosaicked raster image of the primary source maps as well as a simple index map showing the footprint of each source map (see Zientek and others, 2005).

A spatial database map for the Northern Rocky Mountains of Montana, Idaho, and eastern Washington, brings together forty-three 1:100,000- to 1:250,000-scale digital geologic maps into a common database format.

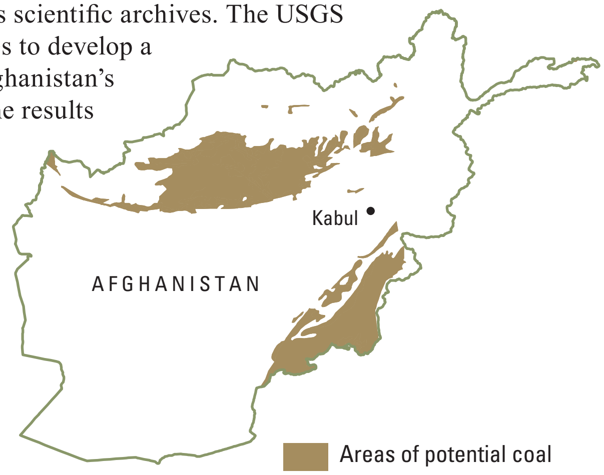


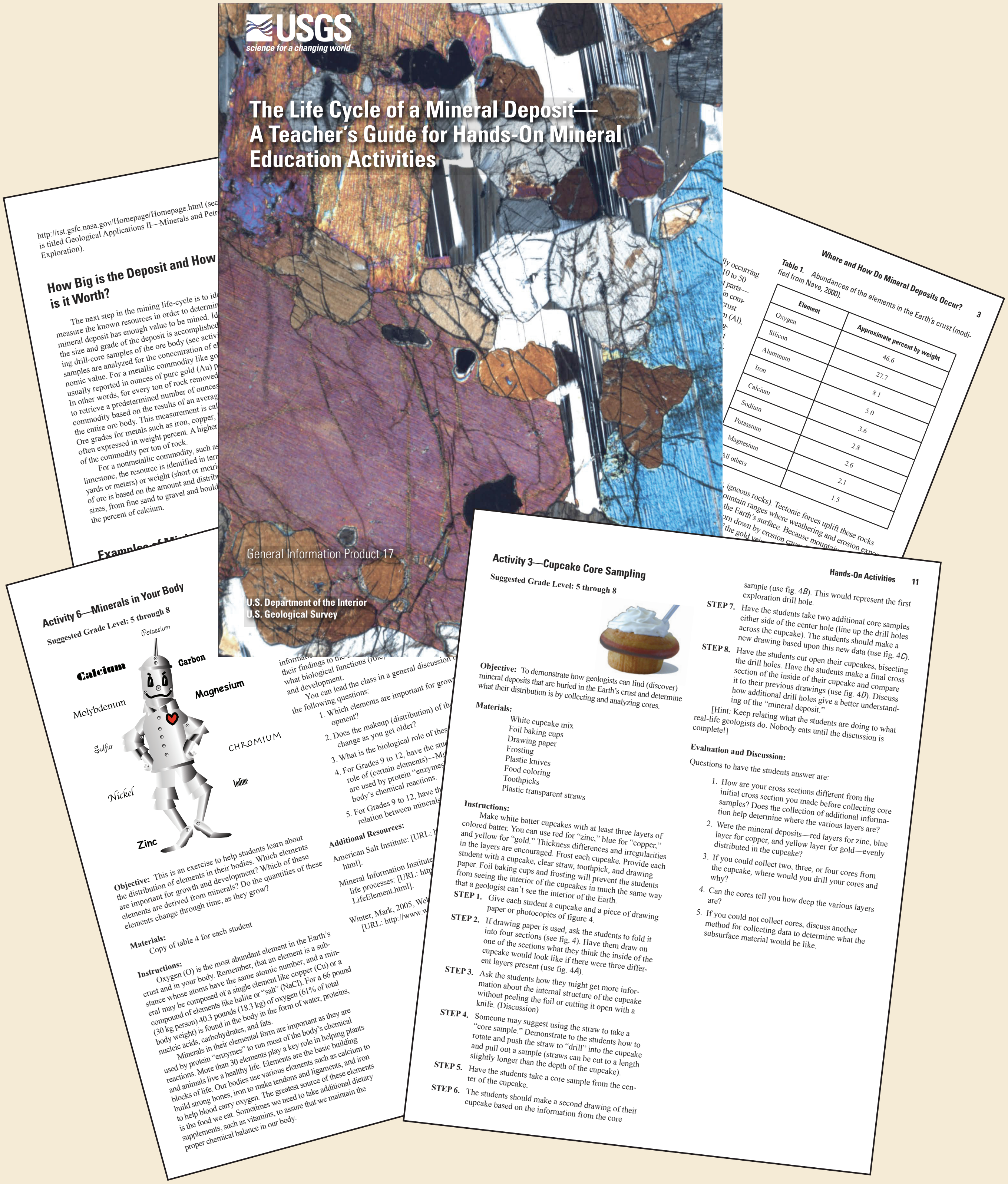
Database for the Geology of the Northern Rocky Mountains—Idaho, Montana, and Washington

This relational database was created to prepare and organize the geologic map-unit and lithologic descriptions for input into the spatial database (Zientek and others, 2005) for the geology of the northern Rocky Mountains. It was released in the Microsoft Access format and contains tables for data, definitions, relationships, and hierarchies, as well as forms used to enter data and queries used to extract data. In addition to the descriptive geologic information for the northern Rocky Mountains region, the database also contains a substantial bibliography of geologic literature for the area. This database is available from the USGS website (Causey and others, 2008).

Large-Scale Digital Geologic Map Databases and Reports of the North Coal District in Afghanistan

Coal is the main source for power generation in Afghanistan; however, development of Afghanistan's coal is limited by a lack of understanding about the locations and reserves of the coal deposits. Afghanistan also lacks the technology to effectively exploit the obvious deposits. From 2004 through 2007, the U.S. Agency for International Development (USAID) contracted the USGS to assess the potential locations and reserves of coal within Afghanistan. To understand the geologic, structural, and tectonic development of the country, GIS databases were compiled for all existing reports, maps, and data associated with rock units that might contain coal within Afghanistan, as well as satellite imagery to better interpret the rock units. All the maps, with and without geographic control, were registered to a controlled satellite image base before GIS compilation. This compilation was conducted in cooperation with the Afghan Geological Survey (AGS). The collaboration not only provided training to AGS personnel in modern methods for coal assessment but also preserved the country's scientific archives. The USGS is now using these databases to develop a better understanding of Afghanistan's potential coal resources. The results of this effort are published in USGS report available on the web (Hare and others, 2008).





USGS
science for a changing world
The Life Cycle of a Mineral Deposit—A Teacher's Guide for Hands-On Mineral Education Activities
General Information Product 17
U.S. Department of the Interior
U.S. Geological Survey
How Big is the Deposit and How
is it Worth?
Where and How Do Mineral Deposits Occur? 3
Table 1. Abundances of the elements in the Earth's crust (modified from Nave, 2000).
Element
Approximate percent by weight
Oxygen 46.6
Silicon 27.7
Aluminum 8.1
Iron 5.0
Calcium 3.6
Sodium 2.8
Potassium 2.6
Magnesium 2.1
All others 1.5
Activity 6—Minerals in Your Body
Suggested Grade Level: 5 through 8
Potassium
Calcium
Carbon
Magnesium
Molybdenum
Sulfur
CHROMIUM
Nickel
Iodine
Zinc
Objective: This is an exercise to help students learn about the distribution of elements in their bodies. Which elements are important for growth and development? Which of these elements are derived from minerals? Do the quantities of these elements change through time, as they grow?
Materials:
Copy of table 4 for each student
Instructions:
Oxygen (O) is the most abundant element in the Earth's crust and in your body. Remember, that an element is a substance whose atoms have the same atomic number, and a mineral may be composed of a single element like copper (Cu) or a compound of elements like halite or "salt" (NaCl). For a 66 pound (30 kg person) 40.3 pounds (18.3 kg) of oxygen (61% of total body weight) is found in the body in the form of water, proteins, nucleic acids, carbohydrates, and fats.
Minerals in their elemental form are important as they are used by protein "enzymes" to run most of the body's chemical reactions. More than 30 elements play a key role in helping plants and animals live a healthy life. Elements are the basic building blocks of life. Our bodies use various elements such as calcium to build strong bones, iron to make tendons and ligaments, and iron to help blood carry oxygen. The greatest source of these elements is the food we eat. Sometimes we need to take additional dietary supplements, such as vitamins, to assure that we maintain the proper chemical balance in our body.
Activity 3—Cupcake Core Sampling
Hands-On Activities 11
Suggested Grade Level: 5 through 8
Objective: To demonstrate how geologists can find (discover) mineral deposits that are buried in the Earth's crust and determine what their distribution is by collecting and analyzing cores.
Materials:
White cupcake mix
Foil baking cups
Drawing paper
Frosting
Plastic knives
Food coloring
Toothpicks
Plastic transparent straws
Instructions:
Make white batter cupcakes with at least three layers of colored batter. You can use red for "zinc," blue for "copper," and yellow for "gold." Thickness differences and irregularities in the layers are encouraged. Frost each cupcake. Provide each student with a cupcake, clear straw, toothpick, and drawing paper. Foil baking cups and frosting will prevent the students from seeing the interior of the cupcakes in much the same way that a geologist can't see the interior of the Earth.
STEP 1. Give each student a cupcake and a piece of drawing paper or photocopies of figure 4.
STEP 2. If drawing paper is used, ask the students to fold it into four sections (see fig. 4). Have them draw on one of the sections what they think the inside of the cupcake would look like if there were three different layers present (use fig. 4A).
STEP 3. Ask the students how they might get more information about the internal structure of the cupcake without peeling the foil or cutting it open with a knife. (Discussion)
STEP 4. Someone may suggest using the straw to take a "core sample." Demonstrate to the students how to rotate and push the straw to "drill" into the cupcake and pull out a sample (straws can be cut to a length slightly longer than the depth of the cupcake).
STEP 5. Have the students take a core sample from the center of the cupcake.
STEP 6. The students should make a second drawing of their cupcake based on the information from the core sample (use fig. 4B). This would represent the first exploration drill hole.
STEP 7. Have the students take two additional core samples either side of the center hole (line up the drill holes across the cupcake). The students should make a new drawing based upon this new data (use fig. 4C).
STEP 8. Have the students cut open their cupcakes, bisecting the drill holes. Have the students make a final cross section of the inside of their cupcake and compare it to their previous drawings (use fig. 4D). Discuss how additional drill holes give a better understanding of the "mineral deposit."
[Hint: Keep relating what the students are doing to what real-life geologists do. Nobody eats until the discussion is complete!]
Evaluation and Discussion:
Questions to have the students answer are:
1. How are your cross sections different from the initial cross section you made before collecting core samples? Does the collection of additional information help determine where the various layers are?
2. Were the mineral deposits—red layers for zinc, blue layer for copper, and yellow layer for gold—evenly distributed in the cupcake?
3. If you could collect two, three, or four cores from the cupcake, where would you drill your cores and why?
4. Can the cores tell you how deep the various layers are?
5. If you could not collect cores, discuss another method for collecting data to determine what the subsurface material would be like.

Training

The USGS stresses the importance of partnerships with the academic community and other Federal and State agencies in maintaining the health of USGS scientific activities. Cooperative agreements currently exist between WMERSC and a number of universities throughout the western United States. These formal agreements extend our research capabilities and resources through student and faculty interaction, by providing access to facilities and support services not available in Center offices, and by exposing staff to a synergistic working environment. These interactions sometimes provide opportunities for Center staff to design and develop training materials and provide hands-on seminars that appeal to a wide variety of end users.

Short Course Introduction to Quantitative Mineral-Resource Assessments

To provide the unbiased information needed in decision-support systems regarding an area's mineral potential, USGS scientists recommend a three-step process in which (1) the geology of the area to be assessed is evaluated for similarities to that of known mineral deposits, (2) frequency distributions of tonnages and grades of well-explored deposits serve as models for grades and tonnages of possible undiscovered deposits, and (3) the number of undiscovered deposits in an area is estimated probabilistically by type. The internally consistent descriptive, grade and tonnage, deposit density, and economic models used in this type of assessment reduce the chances of biased estimates. This short course was developed by a WMERSC scientist to assist policymakers in evaluating the consequences of alternative courses of action with respect to land use and possible mineral-resource development; it presents three sets of slides and supplemental text outlining the general principles, guidelines, and assumptions that are used to produce quantitative mineral-resource assessments. This short course is available for free at a USGS website (Singer, 2008).

The Life Cycle of a Mineral Deposit—A Teacher's Guide for Hands-On Mineral Education Activities

This teacher's guide defines what a mineral deposit is, how it is identified and measured, how the resources are extracted, and how the mining site is reclaimed. It also addresses how minerals and mineral resources are processed and how we use mineral resources in our everyday lives. Included are 10 activity-based learning exercises that educate students on basic geologic concepts; the processes of finding, identifying, and extracting the resources from a mineral deposit; and the uses of minerals. The guide is intended for grades 5 through 8 science teachers and students and is designed to meet the National Science Content Standards as defined by the National Research Council (1996). Several of these activities can be modified to meet the National Science Content Standards for grades 9 through 12. The complete teacher's guide (Frank and others, 2005) is available for free from the USGS.

A GIS Spatial Analysis Course

Resource materials for a GIS spatial analysis course were designed by one of the scientists of the WMERSC. The goal of the class is to introduce the concepts of GIS modeling in which multiple categorical and ordered spatial datasets are combined to predict the distribution or occurrence of the product of some complex process. Examples of the types of applications addressed might be predictive models of animal habitat, occurrence of infectious disease, or undiscovered mineral resources. These types of models are all characterized by complex and sometimes poorly understood processes; that is, the models are not prescriptive, but they are often fuzzy or probabilistic in nature. The course includes exercises that provide experience with multi-disciplinary problems—the kind of problems commonly faced by organizations or groups that manage either land or natural resources. This GIS spatial analysis course (Raines, 2006) is available on the Web.

References

WMERSC staff publishes both within the USGS and in outside publications. The majority of the publications listed below are available on-line from the USGS, and may be accessed via the URL links (if given). One way to locate on-line outside publications is to perform a Google search using the scholar feature found at http://scholar.google.com/.

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Produced in the Western Region, Menlo Park, California
Manuscript approved for publication, October 6, 2010
Edited by Carolyn Donlin
Design and layout by David R. Jones
Cover and illustrations by Jeanne DiLeo

Frank and others—**Western Mineral and Environmental Resources Science Center—Providing Earth Science for Complex Societal Issues**—Circular 1363