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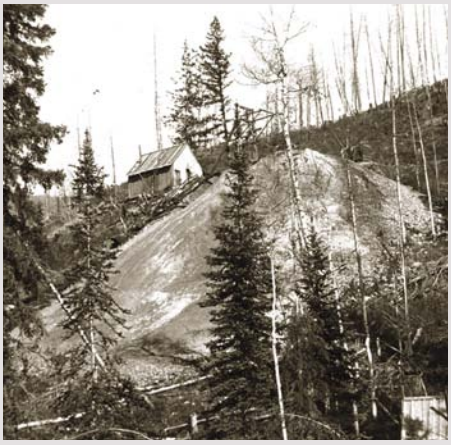
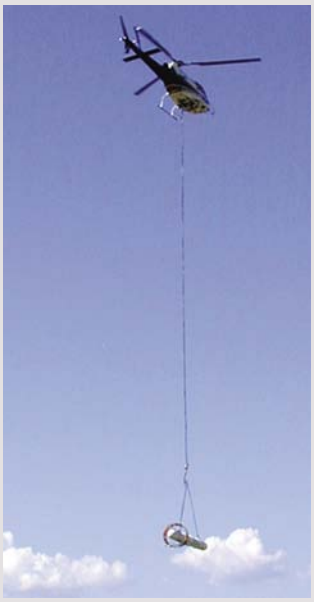
USGS Mineral Resources Program—Supporting Stewardship of America's Natural Resources





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U.S. Department of the Interior
U.S. Geological Survey

USGS Mineral Resources Program—Supporting Stewardship of America's Natural Resources

By S.J. Kropschot

With a section on Evolution of Mineral Resource Assessments

By Kathleen M. Johnson

The USGS Mineral Resources Program provides the Nation with unbiased information about mineral potential, production, consumption, and the environmental effects of mineral resources.

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
P. Lynn Scarlett, Acting Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

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Forward

This volume celebrates more than 125 years of leadership in the science of mineral resources. The U.S. Geological Survey (USGS) was charged in the Organic Act of 1879 with "classification of the public lands, and examination of the geological structure, mineral resources, and products of the national domain." The mission of the USGS has evolved to meet the changing needs of society and to take advantage of advances in science and technology. The current Mineral Resources Program serves the Nation by supporting a wide range of mineral-resource research studies and information collection, analysis, and dissemination activities. The Program has built on the successes of the past and continues to evolve to meet the changing needs of the Nation. Methodologies, techniques, and information developed to conduct mineral resource assessments on Federal lands have made the USGS a leader in collecting and delivering information used to make land-use decisions, to understand issues related to public health, and to ensure a secure and strong economy for the Nation.

P. Patrick Leahy
Acting Director

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USGS Mineral Resources Program—Supporting Stewardship of America's Natural Resources

By S.J. Kropschot

Abstract

The U.S. Geological Survey (USGS) Mineral Resources Program continues a tradition of Federal leadership in the science of mineral resources that extends back before the beginning of the bureau. The need for information on metallic mineral resources helped lead to the creation of the USGS in 1879. In response to the need to assess large areas of Federal lands in the 20th century, Program scientists developed, tested, and refined tools to support managers making land-use decisions on Federal lands. The refinement of the tools and techniques that have established the USGS as a leader in the world in our ability to conduct mineral resource assessments extends into the 21st century.

Evolution of Mineral Resource Assessments

By Kathleen M. Johnson

Nonfuel minerals are essential building blocks of society. They are the materials with which we build our homes and cities, fertilize the crops that sustain life, and provide the wealth that allows us to buy goods and services that we cannot provide for ourselves. However, in contrast to fuel minerals (such as oil, gas, and coal), nonfuel mineral resources generally are not directly used by individual consumers. We buy light bulbs, not the silica, soda ash, lime, coal, salt, tungsten, copper, nickel, molybdenum, iron, manganese, aluminum, and zinc that are required to convert electricity into light. And we buy toothpaste, not the silica, limestone, aluminum, phosphate, fluorine, tin, and titanium that are necessary to keep our teeth healthy.

The United States has enormous mineral wealth, and people have benefited from that wealth from the very earliest days. Salt recovered from sea water by coastal peoples was traded for animal skins hunted by inland peoples long before Europeans arrived in North America. Records of alum, iron, copper, and clay, needed for making bricks, are included in Thomas Hariot's account of the 1585 expedition to Virginia with Sir Walter Raleigh. Iron that was mined from the bogs of the East Coast was used to make weapons in the 18th century. In the 19th century, the growing Nation relied on additional iron resources mined in the Midwestern States to foster industrial growth, such as building transcontinental railroads. The 19th and 20th centuries saw development of mines in the United States for a great many of the nonfuel mineral commodities we require to maintain our standard of living.

The Federal Government owns nearly 650 million acres of land—almost 30 percent of the land area of the United States—and these lands are rich in natural resources, including timber, fuel, and minerals. The Federal agencies responsible for managing America's natural resources must meet both the public desire to protect those resources and the public expectation of economic growth based on them. Within the Federal Government, a number of agencies contribute to the management of natural resources associated with public lands. Among these agencies, the Bureau of Land Management and the Forest Service have responsibility for managing lands for multiple use. The Bureau of Land Management, a bureau of the Department of the Interior, manages a wide variety of resources and uses, including energy and minerals; timber; recreation; forage; wild horse and burro populations; fish and wildlife habitat; wilderness areas; archaeological, paleontological, and historical sites; and other natural heritage values. The Forest Service, a bureau of the Department of Agriculture, manages the national forests for a number of uses, including recreation, timber, wilderness, mineral resources, water, grazing, fish, and wildlife. In support of these missions, the U.S. Geological Survey (USGS) has developed tools to provide information about where undiscovered mineral resources may occur and to estimate the quantity and quality of those resources, in a form that is today known in the USGS as a three-part quantitative mineral resource assessment; the published products are known simply as mineral resource assessments.

The fundamental information provided in a mineral resource assessment includes an estimate of the number of undiscovered deposits, descriptions of their likely grades and tonnages, and general information about their locations and characteristics. For many deposit types, general locations, grades, and tonnages of known deposits have been documented and incorporated into what are known as mineral deposit models. Reproducible methods for estimating numbers of undiscovered mineral deposits have been less completely specified, so this is an area of ongoing research.

—Drew,1997, p. 127

The fundamental information provided in a mineral resource assessment includes an estimate of the number of undiscovered deposits, descriptions of their likely grades and tonnages, and general information about their locations and characteristics. For many deposit types, general locations, grades, and tonnages of known deposits have been documented and incorporated into what are known as mineral deposit models. Reproducible methods for estimating numbers of undiscovered mineral deposits have been less completely specified, so this is an area of ongoing research.

Quantitative mineral resource assessments are not easily understood and have been the source of heated discussions within the USGS, the minerals industry, and the mineral resource community. In 1991, a team of USGS specialists was formed to conduct quantitative mineral resource assessments for 13 wilderness study areas in the western part of the United States. "Of the 13 wilderness study areas, only the Redcloud Peak and the Handies Peak wilderness study areas were found to be highly mineralized, not an unreasonable conclusion given the number of mineral deposits that remained to be discovered in the American west. If as many as 13 land parcels are examined, then it is to be expected that one or two of them will be highly mineralized." (Drew, 1997, p. 171). Taking into account the mineral resource assessments, the Secretary of the Interior decided to recommend that the U.S. Congress not include these two areas in the wilderness system. The Sierra Club Legal Defense Fund sued the Secretary and questioned the scientific methodology used to evaluate the mineral resources of the wilderness study areas. Although the lawsuit was ultimately dismissed, the methodology was thoroughly reviewed and validated. Finally, in January 1993, both wilderness study areas were recommended as not suitable for wilderness (http://www.blm.gov/nlcs/wsa/WSA_Details_7-2005.pdf; accessed Nov. 3, 2005).

In 1998, the USGS released the first-ever national mineral resource assessment for undiscovered deposits of gold, silver, copper, lead, and zinc. These mineral commodities were chosen because, after iron and aluminum, they are the most valuable metals in the economy. They also tend to occur together in nature, thereby introducing efficiencies in the enormous job of estimating undiscovered resources for the entire country. The National Mineral Assessment was conducted by 19 regional assessment teams from the Mineral Resources Program using quantitative assessment methods. As part of the 1998 National Mineral Resource Assessment, a database was compiled for the largest identified resources of gold, silver, copper, lead, and zinc in the United States (Long and others, 1998). The

data collected as part of the 1998 assessment are an invaluable tool for those involved in mineral exploration, land-use planning, and ecosystem management.

In 1999, Program scientists began a feasibility study to consider the possibility of conducting the first-ever global mineral resource assessment. The study identified partners, customers, and the methodology required to undertake the study. In response to the growing demand for information on the global mineral resource base, Program scientists began consistent, comprehensive collection of global mineral resource information and analysis in 2002. The focus of the first stage of the assessment is on copper, because of its importance in electronics and industrial applications; platinum-group metals, because of their critical applications as catalysts in the automobile, chemical, and petroleum industries; and potash, because it is an important component of many fertilizers required for food production. The primary objectives of the global mineral resource assessment are to outline the principal land areas in the world that have potential for undiscovered deposits of these essential resources and to estimate the quantities of those resources to a depth of one kilometer below the Earth's surface.

Making wise choices that lead to a secure supply of mineral commodities requires information regarding the location, quality, and quantity of resources. To this end, the Mineral Resources Program today supports earth science studies that contribute to unbiased quantitative mineral resource assessments. Much of the information gathered in preparation for an assessment, no matter what the scale, involves research that results in reliable basic data with which to understand the geologic history and characteristics of the area to be assessed. Interdisciplinary teams of experts then analyze all available data with a goal of identifying characteristics suggestive of undiscovered mineral deposits and offering clues to the location, quality, and quantity of the undiscovered deposits. These studies address challenges in securing mineral resource supplies for the United States and the minerals-related information needs of other Federal agencies.

Minerals—Why Do We Need Them?

Minerals are a fundamental support for our society. They underpin our economy and impact our daily lives. Since its inception, the U.S. Geological Survey (USGS) has played an essential role in providing basic data, research results, and analysis about mineral resources needed by decisionmakers at many levels. The following pages showcase how mineral resource studies began in the USGS and how these studies have evolved over the years to meet the changing needs of the Nation.

The United States is the world's leading user of mineral commodities. We are surrounded by mineral products, some obvious, others more difficult to recognize. Minerals are a large part of the houses we live in, the cars we drive, and the roads we drive on. They are in the fertilizers used to produce the food we eat, and they are in everything from television sets to pencils to airplanes. Minerals are essential to the lives of all Americans and people everywhere.

Mineral commodities accounted for more than $478 billion in the U.S. economy in 2005. Accurate and up-to-date information about production and consumption of mineral commodities worldwide contributes to maintaining the U.S. economy and our national security. The United States must import 100 percent of 16 important mineral commodities. One example is indium, which is imported primarily from China, Canada, Japan, and France and is used as a thin-film coating in liquid crystal display (LCD) screens. In addition, the United States imports more than 50 percent of 26 other mineral commodities that help drive the economy. Tin, for example, is used to coat other metals to prevent corrosion ("tin cans" are made from tin-coated steel) and

Patterns of consumption per capita of metals and minerals for developed economies have been stable in the latter part of the 20th century, and while there were lower rates of consumption in many developing countries, a number of developing countries have growing consumption per capita. The growth of metals and minerals consumption in developing countries could have a great impact on world mineral consumption.

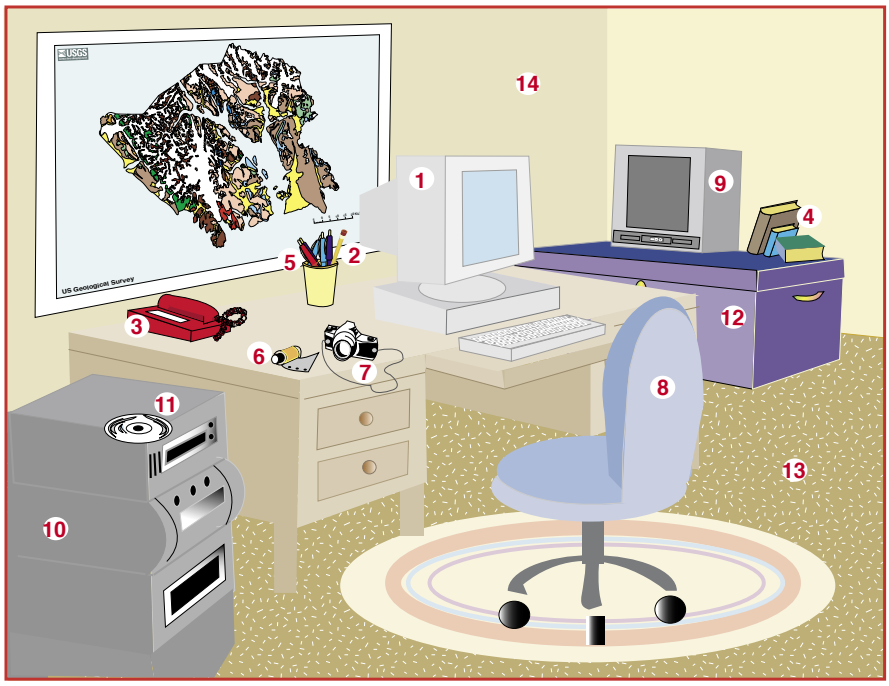
—Morse and Glover, 2002, p. 1.4

as an alloying agent to make such alloys as soft solder, pewter, and bronze; it is imported primarily from Peru, China, Bolivia, and Brazil. Because our economy depends on mineral commodities, it is important for us to understand where mineral deposits can be found, how they are formed, and their effects on the environment, whether they are mined or untouched. Studies of the interactions of minerals with water, plants, and other organisms provide us with a greater understanding of the environment, which, in turn, is essential for understanding human and ecosystem health issues.

USGS Mineral Resources Program

The USGS has provided information on mineral resources since it was first established in 1879. Congress, recognizing the importance of mineral resources, charged the USGS in its Organic Act with the "classification of the public lands and examination of the geological structure, mineral resources, and products of the national domain." In the intervening years, our society has changed and the needs of the Nation have evolved, but our need for mineral resources is greater than ever.

Today, the Mineral Resources Program comprises two major functions that meet the needs of a diverse user community for minerals related information. A research and assessment function provides information for land-use planners and decisionmakers about where mineral commodities are known or suspected to occur in the Earth's crust, about the estimated quantity and quality of those deposits, and about how they interact with the environment. A data collection, analysis, and dissemination function describes current domestic and international production and consumption of about 100 selected mineral commodities for approximately 180 countries. Together these activities provide information for decisions on issues ranging from local land-use planning to national and international economic policy.



1. **Computer**—Includes gold, silica, nickel, aluminum, zinc, iron, petroleum products, and about thirty other minerals.
2. **Pencil**—Includes graphite and clays.
3. **Telephone**—Includes copper, gold and petroleum products.
4. **Books**—Includes limestone and clays.
5. **Pens**—Includes limestone, mica, petroleum products, clays, silica and talc.
6. **Film**—Includes petroleum products and silver.
7. **Camera**—Includes silica, zinc, copper, aluminum and petroleum products.
8. **Chair**—Includes aluminum and petroleum products.
9. **Television**—Includes aluminum, copper, iron, nickel, silica, rare earth, and strontium.
10. **Stereo**—Includes gold, iron, nickel, beryllium and petroleum products.
11. **Compact Disc**—Includes aluminum and petroleum products.
12. **Metal Chest**—includes iron and nickel. The brass trim is made of copper and zinc.
13. **Carpet**—Includes limestone, petroleum products and selenium.
14. **Drywall**—Includes gypsum clay, vermiculite, calcium carbonate and micas.

Minerals are vital components of many of the things we use in our everyday lives. From Weathers and others, 2000.

The Mineral Resources Program has evolved over the years in response to changing needs and opportunities. In 1996 and 2003, the National Research Council of the National Academy of Sciences reviewed the Program and provided guidance concerning Program direction. In 2003, the Council outlined four roles for the Federal Government in mineral resource science and minerals information: (1) provide the Nation a source of unbiased national-scale science and information; (2) perform basic research on mineral resources; (3) function in an advisory role to other government agencies that require unbiased and impartial information to carry out their regulatory and administrative responsibilities; and (4) undertake and support international activities in the national interest. The USGS Mineral Resources Program is the only Federal entity that provides unbiased nonfuel mineral resource assessments, mineral production and consumption information, and research on the characteristics of mineral deposits that affect environmental issues.

Considering the small contribution of direct domestic mineral production to the overall U.S. economy, it might not be apparent that there is a pressing need for a continued U.S. federal presence in mineral science and information. . . .Minerals science and information help society respond to the depletion of known mineral deposits and contribute to the substitution of relatively abundant minerals for increasingly scarce ones. Minerals science and information help develop alternative sources of supply for minerals subject to unexpected supply disruptions. The USGS has carried out these functions in the past and is respected nationally and internationally for the quality of its information. It has the expertise and experience to provide unbiased information on domestic and foreign mineral resources in the future.

—National Research Council, 2003, p. 21

History of Mineral Resource Studies in the USGS

The need for information on metallic mineral resources helped lead to the creation of the USGS in 1879. Clarence King, first Director of the USGS, faced an enormous challenge when he set about establishing the bureau. As described by USGS historian Mary Rabbitt, the "year in which the Survey was established…was one of great monetary uncertainty, when knowledge of precious-metal resources was vital, and one in which the iron and steel industry faced problems in obtaining suitable raw materials, while information about the Nation's mineral wealth, mining, and metallurgical techniques, and production statistics was meager" (Rabbitt, 1989, p. 11).

The desire for mineral resources had already inspired a number of prospecting frenzies in the country. There is evidence that gold was mined in the area near Dahlonega, Georgia in the early 1800s, and by 1829 there were numerous mining operations in place. So much gold was produced in the area that in 1833 a branch of the U.S. Mint was completed in Dahlonega to mint gold coins; however, by that time the production had begun to decrease and the branch only operated for 24 years. In the mid-1800s, the Upper Peninsula of Michigan experienced a mining boom, when interest in native copper deposits led to the opening of the first mine in the Upper Peninsula in about 1845. A few years later, forty-niners rushed to the gold fields of California. A series of booms and busts during the remainder of the century marked the rise and fall of interest in various mineral commodities, particularly gold and silver.

Early Studies of Mining Districts

Initially, USGS work focused on the geology of mineral deposits, including comprehensive studies of three great mining districts—Leadville in Colorado and Comstock and Eureka in Nevada. Each of these districts faced unique mining problems, and the USGS studies helped provide solutions that were applied throughout the west in the late 1800s. USGS studies also provided guidance to prospectors about where to look for new deposits and helped investors evaluate properties for development.

Two years after the USGS was established, the success of reports such as those generated from the studies of these three mining districts prompted Congress to broaden the bureau's purview beyond Federal lands to all lands within the United States. In the ensuing years, USGS geologists would return to these and other areas to gather information on how ores form, to aid in identify-

ing undiscovered deposits, and to study the effects that generations of mining and milling have had on the environments of mineralized areas. The knowledge acquired from these studies has been applied in many areas across the Nation and around the world.

Importance of Mineral Statistics

The first USGS Director, Clarence King, recognized the importance of mineral statistics to the United States economy. Late in the 1870s, closure of California quicksilver mines, which produced mercury necessary for the recovery of gold, accelerated the closure of gold mines in Georgia. However, Director King also recognized that the USGS should not be limited to collecting only production data, because other information, such as sample locality, characteristics of the geologic setting, and the mineralogical and chemical make up of mineral deposits was needed to understand and support mineral resource related research activities. Mary Rabbitt describes how collecting mineral information got started:

> Until Congress authorized the Survey to conduct investigations in the region east of the 100th meridian, the Survey could collect mineral statistics only in the Western States. King, however, was able to make the study of mineral statistics national through the cooperation of the Tenth Census, authorized on the day the Survey was established…Francis A. Walker was appointed Superintendent of the Tenth Census in April 1879...For the collection of mineral statistics, Walker observed, the creation by the act of Congress at the same session of the Geological Survey seemed to offer a most fortunate opportunity. The collection of the statistics and studies of the economic relations of the precious metals, iron, coal, petroleum, copper, lead, quicksilver, and zinc [should] be entrusted to Clarence King. (Rabbitt, 1980, p. 24-25.)

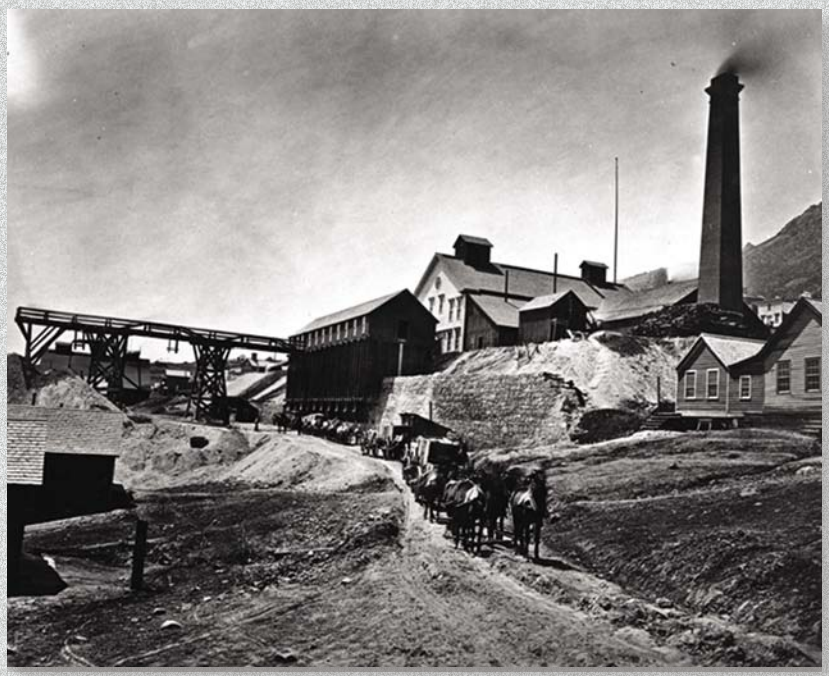
Early data collection activities provided information used to begin the large databases currently supported by the Mineral Resources Program. Although responsibility for collection and maintenance of minerals information has moved in and out of the USGS over the years and the types of statistics that are collected, analyzed, and disseminated have changed over time, the collection of accurate minerals information continues to be an essential function of the Program. Minerals information has proven to be especially useful to Federal, state, and international agencies, to private sector companies interested in minerals availability, defense, security, the economy, trade, environmental management, human health and safety, and to those charged with making sound policy in all sectors of society.

Alaska—The Last Frontier

In 1904, a USGS report highlighting the first 25 years of the bureau noted that Alaska was purchased from Russia in 1867 for $7,200,000, but the Territory of Alaska remained practically forgotten. In 1895, Congress appropriated $5,000 for investigation of gold and coal deposits of Alaska, but interest truly blossomed in 1898 when rich gold deposits were discovered in

Leadville, Eureka, and Comstock—Where it all Began

Why were the Leadville, Eureka, and Comstock mining districts chosen for study by the newly established U.S. Geological Survey (USGS) in 1879? The Federal government was required to buy silver each month under the Bland-Allison Act and was accumulating a gold reserve to back paper currency. This led to a great deal of interest in understanding the domestic sources of gold and silver, and three sites that represented a range of the expected life cycle of mining districts were selected for study.

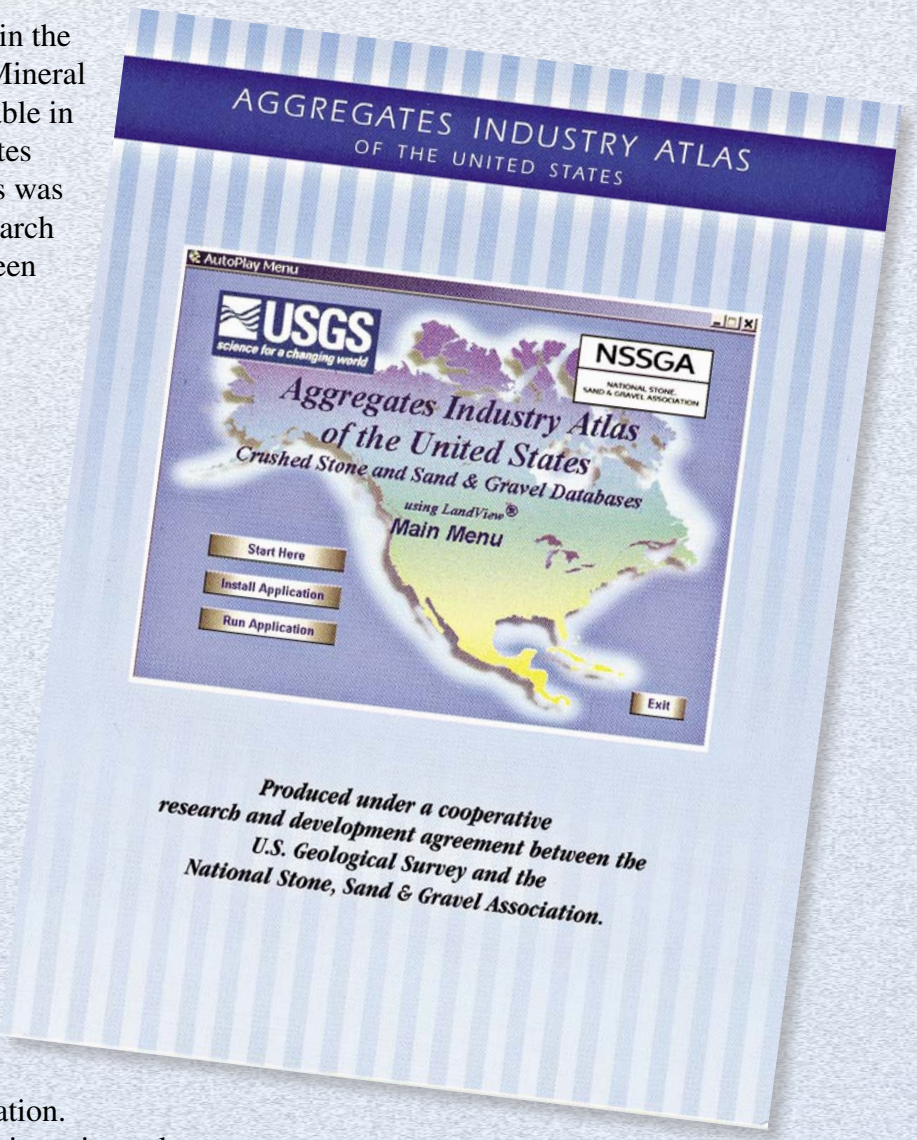


Quartz mill at Virginia City, Nevada, in the Comstock mining district. Photograph by T.H. O'Sullivan was taken during the U.S. Geographical Exploration of the Fortieth Parallel, which investigated the Virginia City area during the winter of 1867-68. From USGS photographic library collection.

- Leadville was new: In the late 1800s, silver-lead deposits in the Leadville mining district of Colorado were just coming into production. The mining camp that grew to be known as Leadville was established after gold was discovered in 1860, but when the gold ran out it was mostly abandoned. What was left was transformed almost overnight by a silver boom in the 1880s when A.B. Wood and his associates claimed expired gold placers and showed that a profit could be made in silver, in spite of the high cost of transporting the ore to St. Louis for smelting.
- Eureka was in its prime: Discovered in 1864, mineral deposits in the Eureka mining district of central Nevada were considered to be more completely developed than any of the other silver-lead deposits in the country when it was selected for study. In addition, litigation under the new 1879 mining law about what constituted a lode in the Eureka mining district centered on a particular limestone zone in an area of extensive faulting. The opportunity for a complete study of the district to help resolve this problem contributed to its selection for study by the newly formed USGS.
- Comstock was beginning to decline: The Comstock mining district in Nevada was considered to be near the end of its production life when it was selected for study, having produced $300 million in gold and silver bullion since 1860. However, the origin of the Comstock lode was still the subject of great scientific debate. Because it had the deepest mines in North America and about 185 miles of workings, the Comstock mining district provided an excellent opportunity to investigate the geologic environment associated with the mineral deposits.

Aggregates Map Helps Rescue Miners

Minerals information collected in the U.S. Geological Survey (USGS) Mineral Resources Program is made available in a variety of formats. The Aggregates Industry Atlas of the United States was produced under a cooperative research and development agreement between the USGS and the National Stone, Sand, and Gravel Association. Released for distribution in January 2002, this CD-ROM contains geographic information system software and two searchable data bases for crushed stone (2,695 entries) and sand and gravel operations (3,485 entries). Data layers from the USGS and U.S. Census Bureau, such as roads, railroads, and congressional districts, are also included. The atlas was designed to be useful to architects and civil engineers, plant managers, construction contractors, land-use planners, sales and marketing professionals, Congressional offices, and state and county legislators. No one, however, expected it to be a key factor in a mine rescue operation.



In July 2002, disaster stranded nine miners deep in a flooded coal mine in Somerset, Pennsylvania. David Lauriski, the Assistant Secretary of the Mine Safety and Health Administration, recalled having seen the Aggregates Industry Atlas at an international trade show. Using information in the atlas, officials from his agency were able to provide emergency workers at the site with a list of aggregate quarries in the area that had the equipment and personnel needed to aid in the rescue efforts. This information was instrumental in saving the lives of the nine miners, who had been trapped for more than three days in a partially flooded chamber 240 feet underground.

In 2002, information from this publication crucially helped guide swift rescue efforts that saved the lives of nine trapped coal miners.

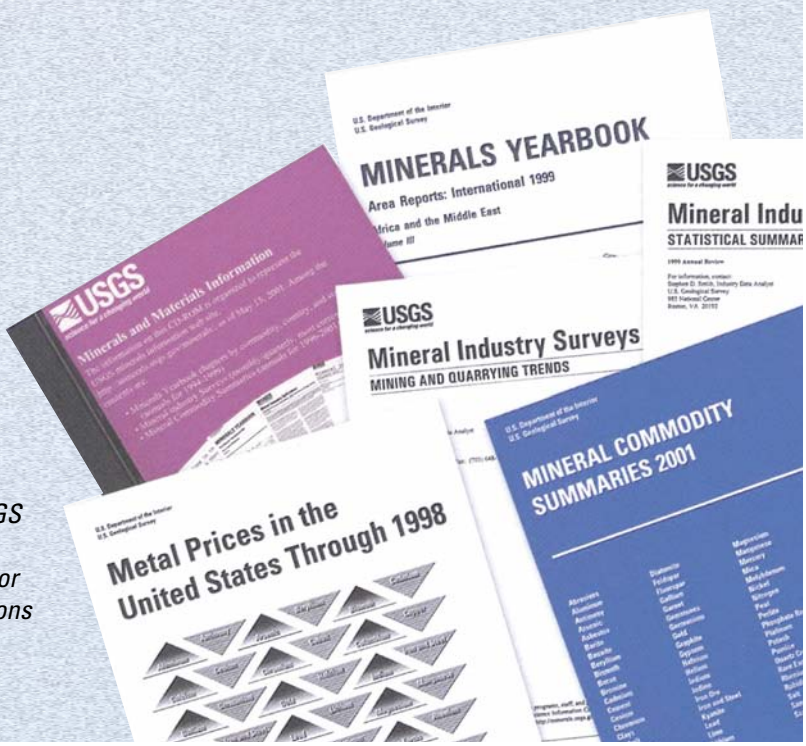
USGS Minerals Information—Decades of Added Value

Before the establishment of the U.S. Geological Survey (USGS), collection of mining statistics was the responsibility of the Commissioner of Mining Statistics, a position created in 1866 in the U.S. Department of the Treasury. When the USGS was formed in 1879, Congress authorized the new agency to collect mineral statistics in the Western States. In 1880, this activity was extended nationwide because the collection of mineral information was required as part of the 10th Census.

When the U.S. Bureau of Mines was created in 1910, the Division of Mines and Mining moved from the USGS to the new organization. The first Bureau of Mines Director, Joseph A. Holmes, was successful in demonstrating the value of economics and statistics. In 1913, the mission of the Bureau of Mines was expanded to include conducting "scientific inquiries . . . with a view to . . . increasing economic development . . . in the mining, quarrying, metallurgical, and other mineral industries."

In 1925, the USGS Division of Mineral Resources, responsible for minerals information reporting, was moved into the Bureau of Mines, which was then transferred to the Department of Commerce under Secretary Herbert Hoover. In 1934, the Bureau of Mines was moved back to the Department of the Interior. The mineral industry data collection program was accelerated in the 1940s, reflecting the broadening government interest in activities that follow mineral extraction and increasing demand for minerals data by defense and emergency preparedness agencies. In the 1970s, responsibility for energy mineral statistics was transferred to the U.S. Energy Information Administration in the Department of Energy.

The Bureau of Mines continued to collect minerals information until the agency was defunded by Congress in 1996. At that time, the collection of information for selected minerals was transferred to the USGS Mineral Resources Program. Today, domestic and international partnerships allow mineral specialists to gather information from domestic and international government, university, and industry representatives. Domestic mineral data are collected through voluntary cooperation of the mineral industry. This special partnership with mineral producers and consumers has enabled production of high-quality statistics and represents a substantial in-kind contribution to this publicly available national information resource by industry.



Through partnerships with industry and government organizations, both domestic and international, the USGS Mineral Resources Program produces and publishes high-quality statistics on the mineral industries—a major national information resource. These sample publications were highlighted by the National Mining Association's monthly publication Mining Voice in October 2001.

the Klondike region, triggering a massive gold rush. During the next few years, USGS attention was focused on gold placers, the largest producers of wealth in the territory. However, in spite of the gold rush, general knowledge of Alaska was still limited (U.S. Geological Survey, 1904, p. 33).

USGS mineral resource investigations were expanded by Congress in 1904 to include, among other things, "a very practical investigation of the costs and methods of placer mining in Alaska for comparison with those in the Yukon Territory and British Columbia," which concluded that some mining techniques used in Alaska were crude and inefficient, and that there was a "complete lack of adequate means of transportation in Alaska in contrast to the exceptionally good roads in Canada" (Rabbitt, 1986, p. 24-25). During the next few years, a series of major reconnaissance surveys by the USGS into the frontier of Alaska expanded information about resources of the territory. These surveys continued through the onset of World War II and demonstrated the need to identify good routes for roads and railroads to mining districts.

Strategic Mineral Resources

Our current thinking about strategic minerals has its roots in the early 20th century, when the stage was being set for the First World War. In 1914, when war broke out in Europe, people in the United States assumed the war would be over quickly and thus would have limited impact on the lives of most Americans. Although the United States was not initially involved in the war, government officials called for a survey of minerals critical to the economy. The survey identified five mineral commodities that the U.S. did not have in adequate supply: tin, nickel, platinum, nitrates, and potash. At the time of the survey, the only

USGS geologist A.H. Brooks examining a section of gold-bearing gravels and sands along Sweetcake Creek, a tributary of Ophir Creek on the Seward Peninsula of Alaska in 1900. From USGS library collection of A.H. Brooks photographs.

ongoing exploration activity in the United States for these commodities was for potash, used in fertilizer.

As the war in Europe dragged on and normal trade was disrupted, European allies relied heavily on the United States for steel, copper, and explosives. Within 2 years of the start of the war, it was clear that U.S. reserves of more than a dozen mineral commodities were inadequate to meet demand. By the time the United States entered the war in 1917, the importance of access to resources was recognized at the highest levels of government, and studies of strategic mineral sources became increasingly important as it became clear that domestic supplies of key commodities were inadequate in quantity, quality, or both.

[On the eve of World War I,] geologists were aware—and others would soon become aware—that no nation is completely self sustaining in mineral resources. All nations depend on others for certain minerals or for markets for their excess minerals.
—Rabbitt, 1986, p. 179-180

Toward the end of the First World War, USGS scientists studied the distribution of the world's reserves of essential minerals in order to furnish U.S. representatives at the Peace Conference with vital economic data. "The study was intended to serve two general purposes: to obtain a clear understanding of the relations between American war needs and foreign sources of supply from which these needs must or could be met; and to obtain an understanding of the bearing of mineral resources on the origin and conduct of the war and on political and commercial readjustments that would follow the end of hostilities" (Rabbitt, 1986, p. 193). Mineral resource geologists were sent to the Caribbean, Central America, and South America to gather information as part of this study.

After the war ended in 1918, recognition of the importance of ensuring an adequate source for strategic minerals continued, and in 1938, strategic mineral resource investigations were supported by funds from the Public Works Administration. The Strategic Minerals Act, passed in June 1939, appropriated funds for strategic minerals studies only days before World War II began. There was concern that the United States might be cut off from foreign sources of key metals prior to the outbreak of war, and mineral resource specialists in the USGS and the U.S. Bureau of Mines were busy identifying possible domestic sources for strategic minerals.

These efforts to plan for future needs, however, shifted abruptly when the United States went to war after Pearl Harbor was attacked in December 1941. The search for resources necessary to support the war effort expanded from the United States to Central America, South America, and the Caribbean, under the auspices of the State Department and the Board of Economic Warfare. In addition to the search for new resources, activities such as recycling and the development of alternatives to selected metallic mineral resources were undertaken during World War II.

Availability of and access to mineral resources continued to be an important component of U.S. policy in the period following World War II. Raw-material price increases and concern about dependence on developing economies for mineral commodities refocused attention on mineral resource exhaustion and supply disruptions as threats to the U.S. economy and national security in the Cold War era. The USGS Mineral Resources Program has been and continues to be a key source of research and information on potential for, production of, and consumption of nonfuel mineral resources.

It is startling to realize that the rise of the industrial age has so accelerated the demand for minerals that we have dug and consumed more mineral resources within the period embraced by the two world wars than in all preceding history. This insatiable demand for minerals to feed the hungry maw of industry and armament has made sources of supply that we used to think were adequate, now look relatively small, and sources of large supply are becoming fewer and fewer.
—Bateman, 1952

Exploration Geochemistry, Geophysical Techniques, and Remote Sensing

Analytical chemistry has long been used by the USGS to help determine the distribution of elements and their relative abundances in the Earth. Chemistry proved to be useful in the early days of mineral exploration, when most deposits were exposed at the surface of the Earth and most exploration was done by pick, shovel, gold pan, and assay. The first USGS chemistry laboratory was organized in 1880, and the use of mobile chemistry laboratories dates back to the early 1900s, when horse-drawn wagons carried necessary reagents, glassware, and equipment

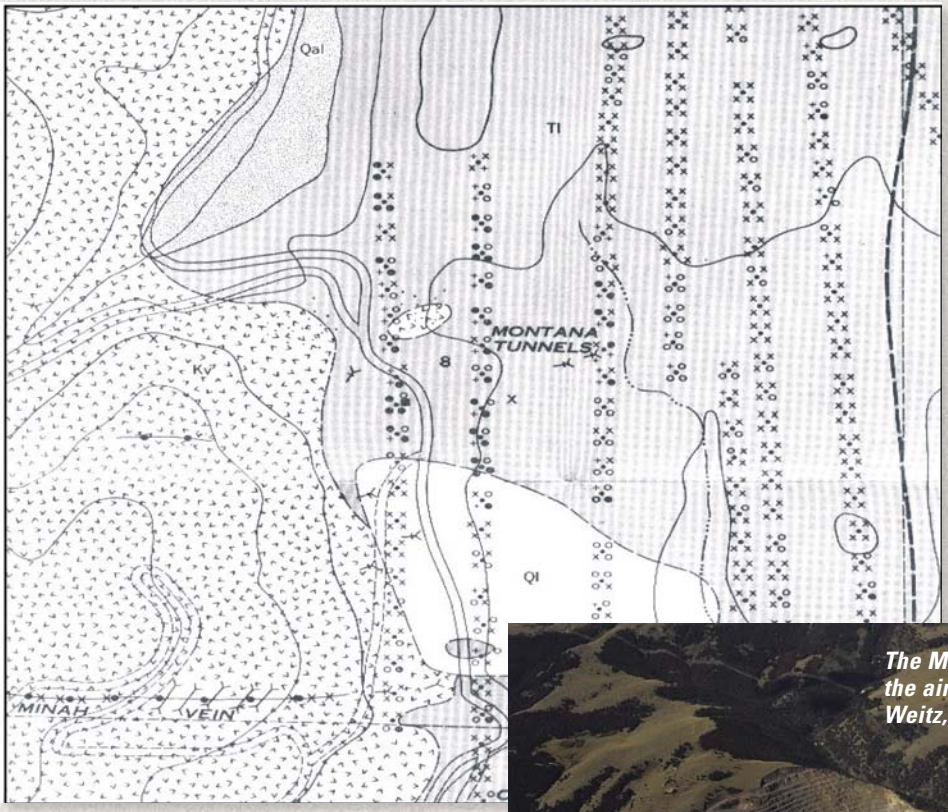
that could be set up and used in a tent. As time went on, new techniques and methodologies in analytical chemistry were developed to help locate and identify mineralized areas, especially those hidden beneath the surface.

Near the end of World War II, geologists from the USGS and the Geological Survey of Canada collaborated on research to develop methodologies for finding buried or hidden mineral deposits using chemistry. It was discovered that very small (trace) amounts of elements in soils and stream sediments could be used as indicators for undiscovered mineral deposits by identifying elemental halos around the deposits. Chemists from both organizations developed methods of detecting and measuring parts-per-million amounts of many of the elements associated with various mineral deposits. The science of geochemistry had come to the USGS. Simple field tests were developed to determine trace amounts of important elements like copper and zinc in stream sediment, soil, and water. These early tests were crude and the amount of a specific element present in the sample was hard to quantify, but the tests were good enough to quickly establish the presence or absence of these elements.

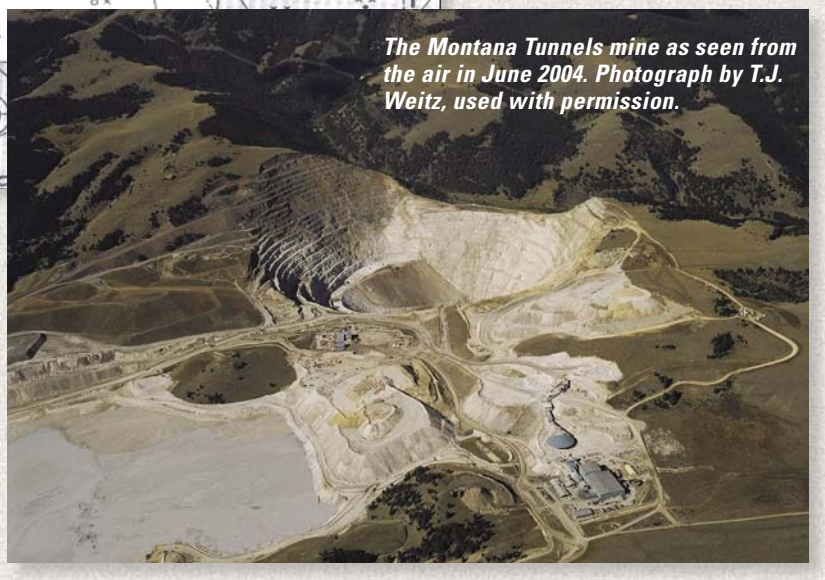
Portable analytical equipment was transported by wagon in 1907 to help determine the distribution of elements while conducting field work in Montana. The analyst could perform wet chemical analyses in a tent when camp was established. (From Taggart, 1995; R.W. Stone, photographer.)

Early Soil Survey Study Leads to Major Metals Discovery

In the late 1940s and early 1950s, there was a large effort by the U.S. Geological Survey (USGS) to map and understand the general geology and mineral deposits in and around the Boulder Batholith in Jefferson and Lewis and Clark Counties, Montana. As part of this work, USGS geologist G.E. Becraft decided in 1956 to test a new analytical technique. This technique, a small-scale soil survey, was designed "to determine whether indications of ore could be found by geochemical methods." Samples collected at 200-foot intervals along north-south lines 500 feet apart were analyzed spectrographically—some were found to contain anomalous amounts of silver, lead, copper, manganese, and zinc. An area that had been mined previously, known locally as the Montana Tunnels, was found to have high metal content in the soil. Becraft concluded that "high metal content probably indicates that a moderately large area is underlain by mineralized rock and could indicate a deposit suitable for open-pit mining methods" (Becraft and others, 1963, p. 53). More than 20 years later, a field geologist working in the area used these results to focus his exploration activities. After exploratory drilling, Centennial Mineral Ltd. obtained permits to mine in 1986; the Montana Tunnels mine was soon in full production for silver, lead and zinc and is projected to be in production through 2011 (Levell, 2004).



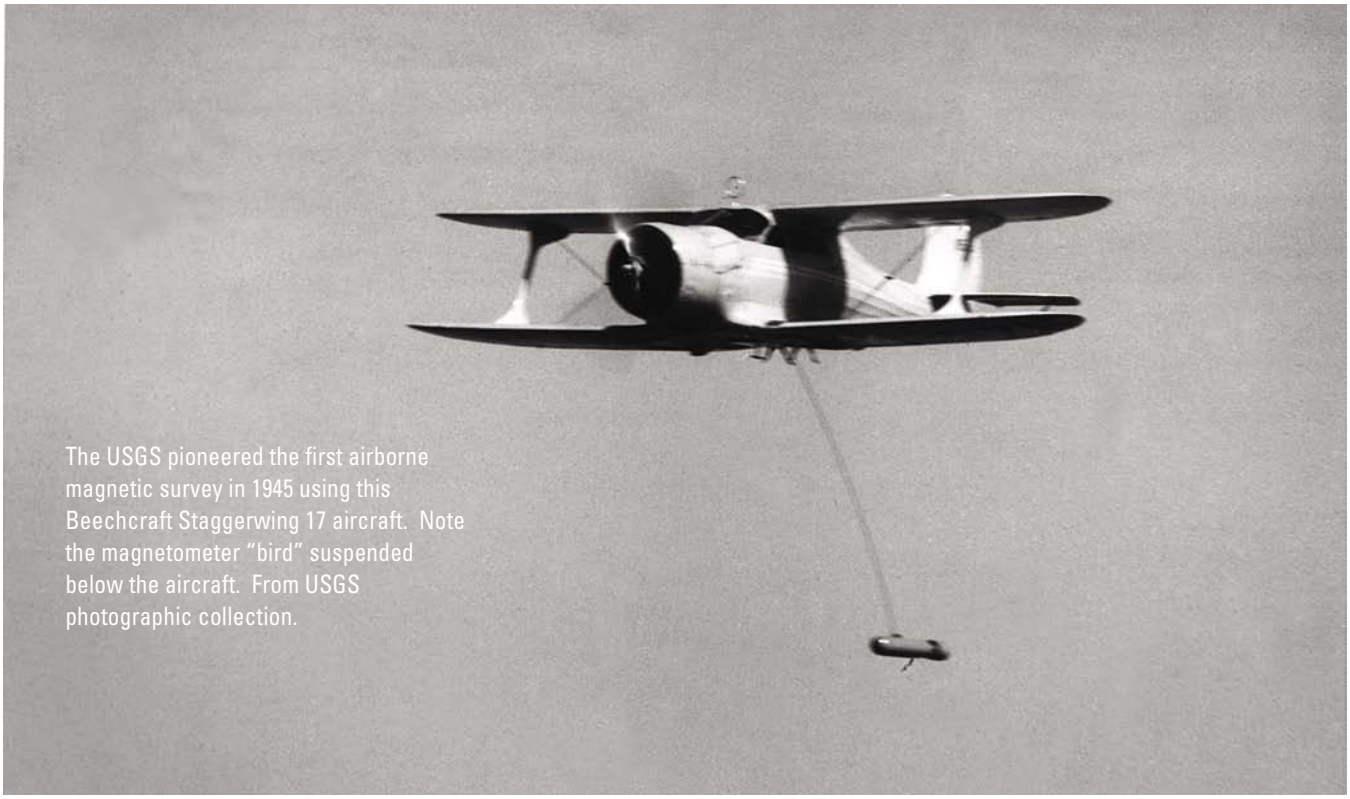
Evidence of early prospecting was identified by G.E. Becraft at Montana Tunnels, and the area became the site selected for an early soil survey in 1956. This map (Becraft and others, 1963, pl. 5) shows the sample localities of the 1956 soil survey.



The Montana Tunnels mine as seen from the air in June 2004. Photograph by T.J. Weitz, used with permission.

The search for mineral resources needed to support the war effort was further aided by another new method, airborne magnetic surveying, which was developed by USGS scientists in cooperation with colleagues from the U.S. Navy. The first airborne magnetic survey was flown in 1945 to test whether magnetic anomaly data could provide a means of "seeing through" nonmagnetic rocks and cover, such as vegetation, soil, desert sands, glacial till, manmade features, and water, to reveal variations in magnetic rocks and structural features, such as faults, folds, and dikes. Results showed that magnetic anomalies reflect variations in the distribution and type of magnetic minerals—primarily magnetite—in the Earth. This technique allows mapping bodies of magnetic rock from the surface down to great depths, depending on such things as their dimensions, shape, and magnetic properties. In many cases, examining magnetic anomalies is the fastest and most cost-effective way to accurately map geologic features and mineral deposits at depth.

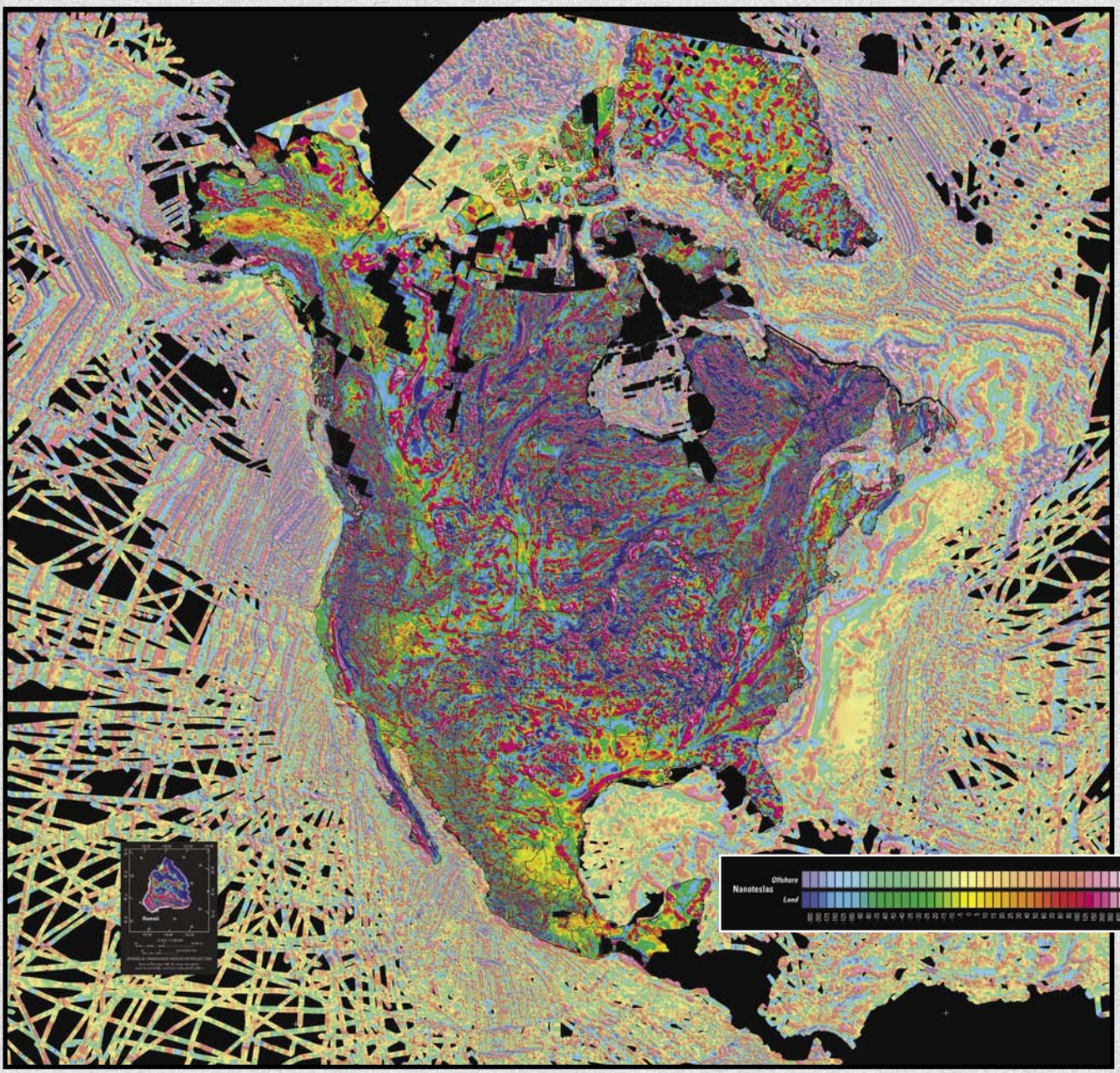
Remote sensing, which has become a tool for the identification of mineral resources, evolved from photogeology, the study of geologic features by means of aerial photographs. With the launch of the early National Aeronautics and Space Administration (NASA) satellites in the late 1970s, USGS scientists moved from visual examination of aerial photographs to analysis of digital, multispectral images aided by laboratory analysis of samples collected from the surveyed area. Over the years, increasingly sophisticated instruments have provided higher spatial and spectral resolution. Dramatic changes in the field of remote sensing have resulted from advances in laboratory and field instruments to better measure spectral detail and the advent of more powerful computers to process the data. In the past 20 years, remote sensing applications have expanded into infrared, near infrared, and thermal emission spectra, and global positioning system (GPS) receivers have made precise geographic location possible. Quantitative, high-resolution measurements can now be made remotely over a wide spectral range. Mineral and rock characteristics on Earth and on other planetary bodies can be identified for mineral exploration as well as in support of space science.



The USGS pioneered the first airborne magnetic survey in 1945 using this Beechcraft Staggerwing 17 aircraft. Note the magnetometer "bird" suspended below the aircraft. From USGS photographic collection.

Magnetic Anomaly Map of North America

In 2002, the U.S. Geological Survey (USGS) released a digital magnetic anomaly database and map for the North American continent, a product of a joint effort by the Geological Survey of Canada, the USGS, and the Consejo de Recursos Minerales of Mexico. The map, derived from the digital database, provides a comprehensive magnetic view of the North American continent, facilitating our understanding of regional geology and allowing study of continental-scale trends. The information can be used to study mineral and energy resources, earthquake and landslide hazards, and hydrologic and environmental problems. The magnetic anomaly database and map have already enabled delineation of structures related to a mid-continental rift buried under younger sedimentary rocks in Minnesota and Wisconsin, refinement of a delineated earthquake hazard zone in the Pacific Northwest, and identification of both mineral and water resources in southern Arizona (Finn, 2002).



Mapping Acid Rock Drainage Using Remote Sensing

Leadville Mine, Lenado, Pitkin County, Colorado, 1908. Photograph by J.E. Spurr.

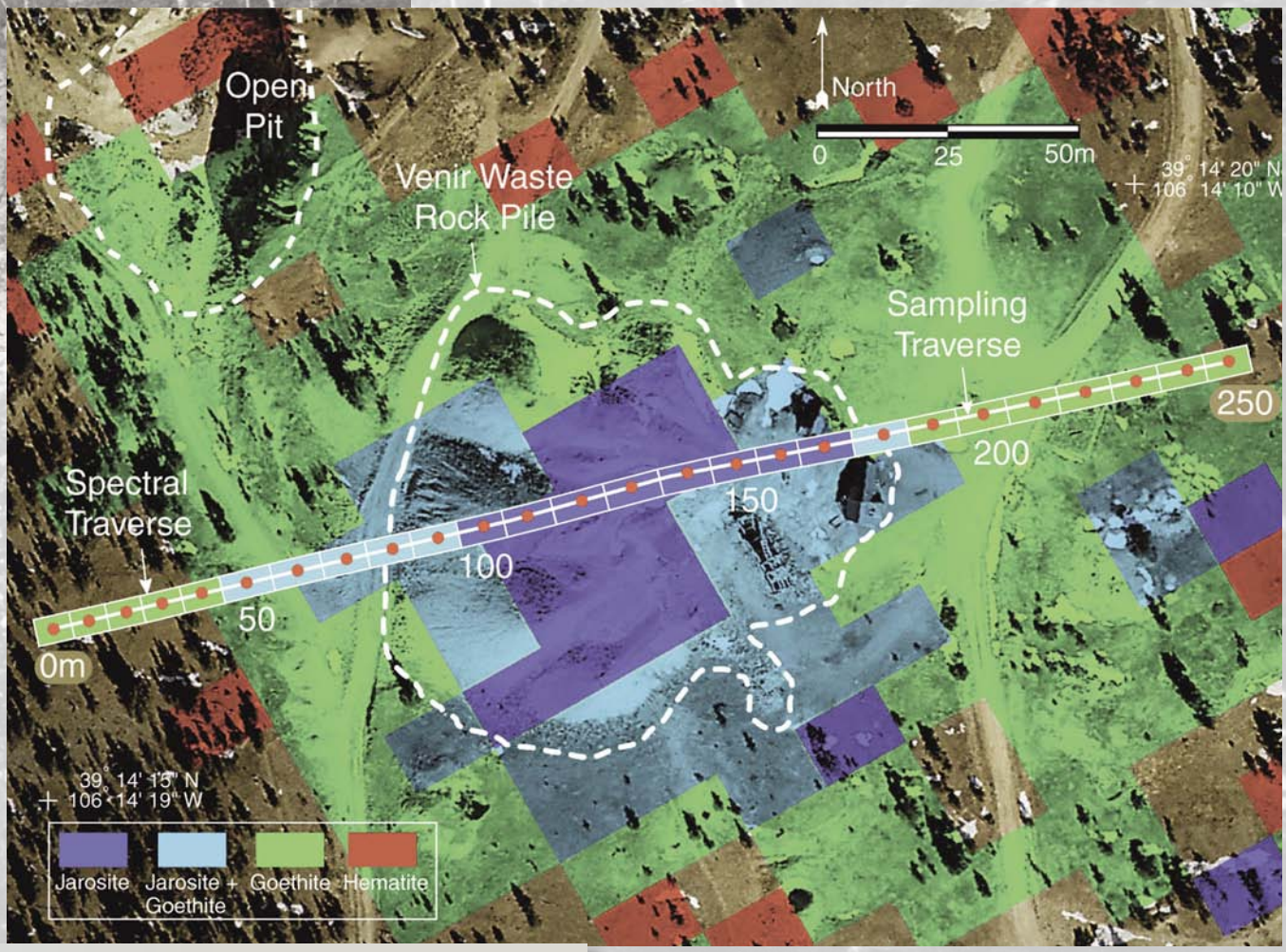
U.S. Geological Survey (USGS) scientists first began studying the Leadville mining district, located approximately 100 miles southwest of Denver, Colorado in 1879. Although silver mining activities in the Leadville area were at their peak from the late 1880s until the silver crash of 1893, mining continues in the area to this day. In 1983, the Environmental Protection Agency (EPA) listed the California Gulch site, which encompasses most of the Leadville mining district, on the National Priority List as part of the Superfund cleanup process. The EPA was concerned about the impact of mine drainage and heavy metals in Arkansas River sediments on the quality of drinking water and the health of riparian ecosystems.

In 1995, EPA contracted with the USGS Mineral Resources Program to help identify the source of acid mine drainage at the California Gulch site. Program researchers determined that the site was an ideal place to test new techniques for rapidly screening large areas and identifying smaller areas for more detailed study. These new techniques rely on data collected by aircraft-mounted sensors (using an Airborne Visible/Infrared Imaging Spectrometer or AVIRIS) that is validated by samples collected on the ground to verify minerals and suites of minerals identified from the remotely sensed data. The test at California Gulch proved successful; scientists were able to identify signatures in the spectral data that identified small areas where specific minerals associated with acid rock drainage were exposed at the surface.

Color-coded maps showing minerals that occur at the surface were generated from the AVIRIS data for the California Gulch site. Scientists identified a small area for additional study within the Superfund site where distinct concentric zones of secondary iron minerals occurred. These secondary iron minerals, when exposed at the surface, might result in acid drainage. The targeted area was sampled and chemical and mineralogical analysis confirmed interpretation of the AVIRIS data (Swayze and others, 2000).

After additional refinement, the method proved to be a successful screening tool for identification of acid-generating minerals exposed at the surface and a way of rapidly evaluating the potential for acid drainage. The EPA manager of the California Gulch site believes that using "the AVIRIS data and technology provided an estimated $2 million saving in site investigation study expenditures…and resulted in shortening the site investigation process by an estimated 2 ½ years" (M.H. Dodson, Environmental Protection Agency, written commun., 1997).

Color-coded map of surface minerals at the California Gulch site, Colorado. The airborne imaging spectrometer (AVIRIS) records images at many different wavelengths. Scientists are able to interpret data and distinguish minerals, because different wave lengths of light are absorbed differently by each mineral or group of minerals. Iron oxide minerals, such as hematite, jarosite, and goethite, were keys to identifying specific areas that had potential acid drainage and required additional study by the Environmental Protection Agency as part of the remediation work at the site. The area near the Venir mine waste rock pile was selected for collection of samples every 10 meters along a 250-meter traverse to check the accuracy of the AVIRIS data. The AVIRIS data proved to be accurate.



AVIRIS data and technology provided an estimated $2 million saving in site investigation study expenditures...and resulted in shortening the site investigation process by an estimated 2 ½ years.
—M.H. Dodson, Environmental Protection Agency

Assessing Mineral Resources on Federal Lands

In the decades after World War II, interest in strategic minerals remained high, but the focus of USGS studies shifted to assessing the potential for undiscovered mineral resources on Federal lands. Although USGS geologists had long worked in known mining districts and had begun assessing the potential for mineral resources in specific areas just before World War II, the challenge of conducting mineral resource assessments on a larger scale and in less well studied areas necessitated the development of new tools and methodologies.

The Wilderness Act of 1964 made 9.1 million acres of national forest lands part of the National Wilderness Preservation System, to be managed without commercial use and construction of permanent roads and buildings. The enabling legislation required that the USGS and U.S. Bureau of Mines assess the mineral resources of each area proposed or established as wilderness, if no prior mineral survey had been made. Subsequent legislation included additional acreage managed by other Federal agencies, including the Bureau of Land Management and National Park Service. Federal agencies continue to identify acreage that require mineral resource assessments today. Research to support this massive effort intensified as techniques and methods to evaluate undiscovered resources were developed and refined. In order to simplify the assessment process, improve the reproducibility of the results, and ensure that the insights derived from years of basic research on mineral deposits are included in every assessment, mineral scientists continue to develop and refine models that are used to evaluate the quantity and quality of undiscovered resources. Ongoing research demonstrates that estimates can be improved by using frequencies of deposits per unit of permissive area (mineral deposit density models) in control areas in the same way that grade and tonnage frequencies of known deposits are used as models of sizes and qualities of undiscovered deposits.

Alaska Mineral Resource Assessment

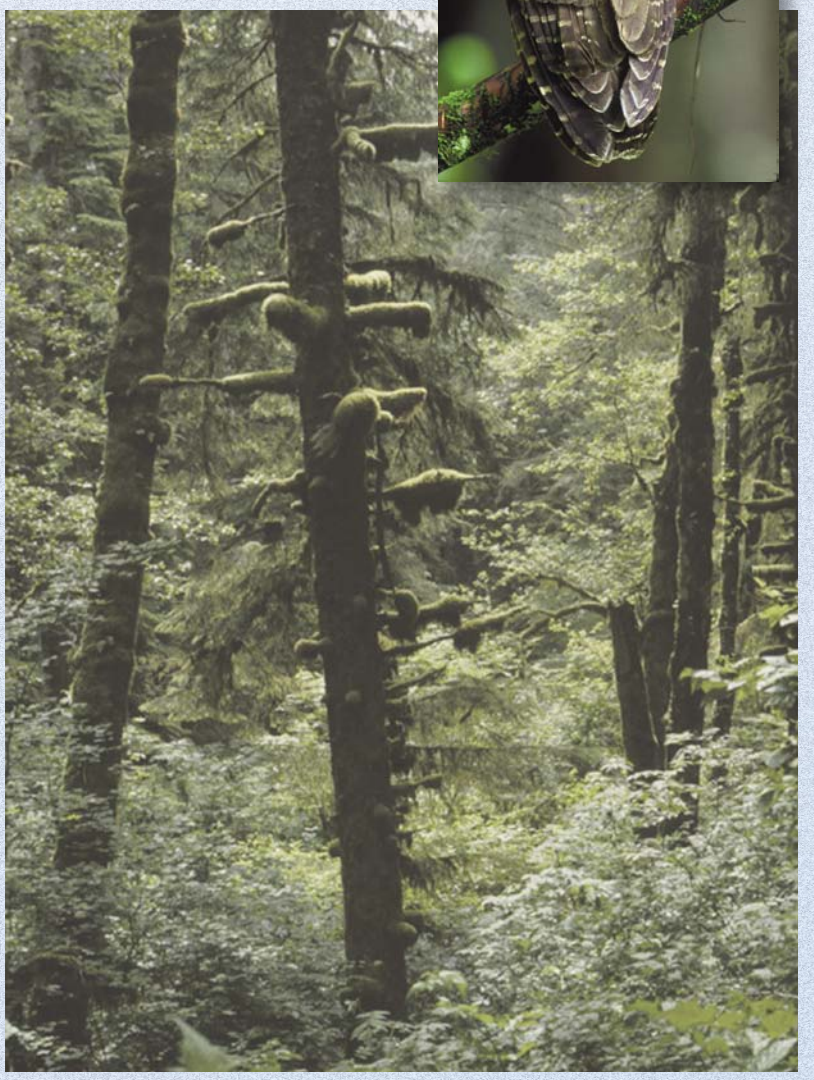
The 1960s also brought renewed interest in Alaska, which was regarded as a potentially great, but largely unknown, reservoir of resources. In response to a perceived impending shortage of minerals materials to supply U.S. industries, Congress authorized a large interdisciplinary project to conduct a rapid inventory of Alaska's mineral resource endowment. The project included geologic mapping and other field and laboratory studies to provide information with which Federal and State agencies, industry, and Native corporations could make informed decisions related to land use and development required under the Alaska Native Claims Settlement Act (ANCSA) and the Alaska National Interest Lands Conservation Act (ANILCA).

Because mineral resource assessments of such large, remote, and little-known regions in Alaska were largely experimental, the project was divided into two phases. The first phase, called the prototype Alaskan Mineral Resource Assessment Program, was a 2-year experimental project designed to develop specific guidelines, techniques, and products as a model for a State-wide mineral inventory. The second phase of the program, known as the Alaskan Mineral Resource Assessment Program (AMRAP), was a long-range plan to perform mineral resource assessments for all of Alaska. Simultaneous with this activity, the Program undertook a regional Alaska Mineral Resource Assessment Project to provide rapid regional-scale information on the potential for undiscovered metallic mineral deposits in support of land decisions being made by the State of Alaska in the 1970s as part of the ANCSA and ANILCA activities. These mineral resource assessments have resulted in the identification of countless areas with potential for undiscovered mineral resources. Discoveries of mineral deposits in some of these

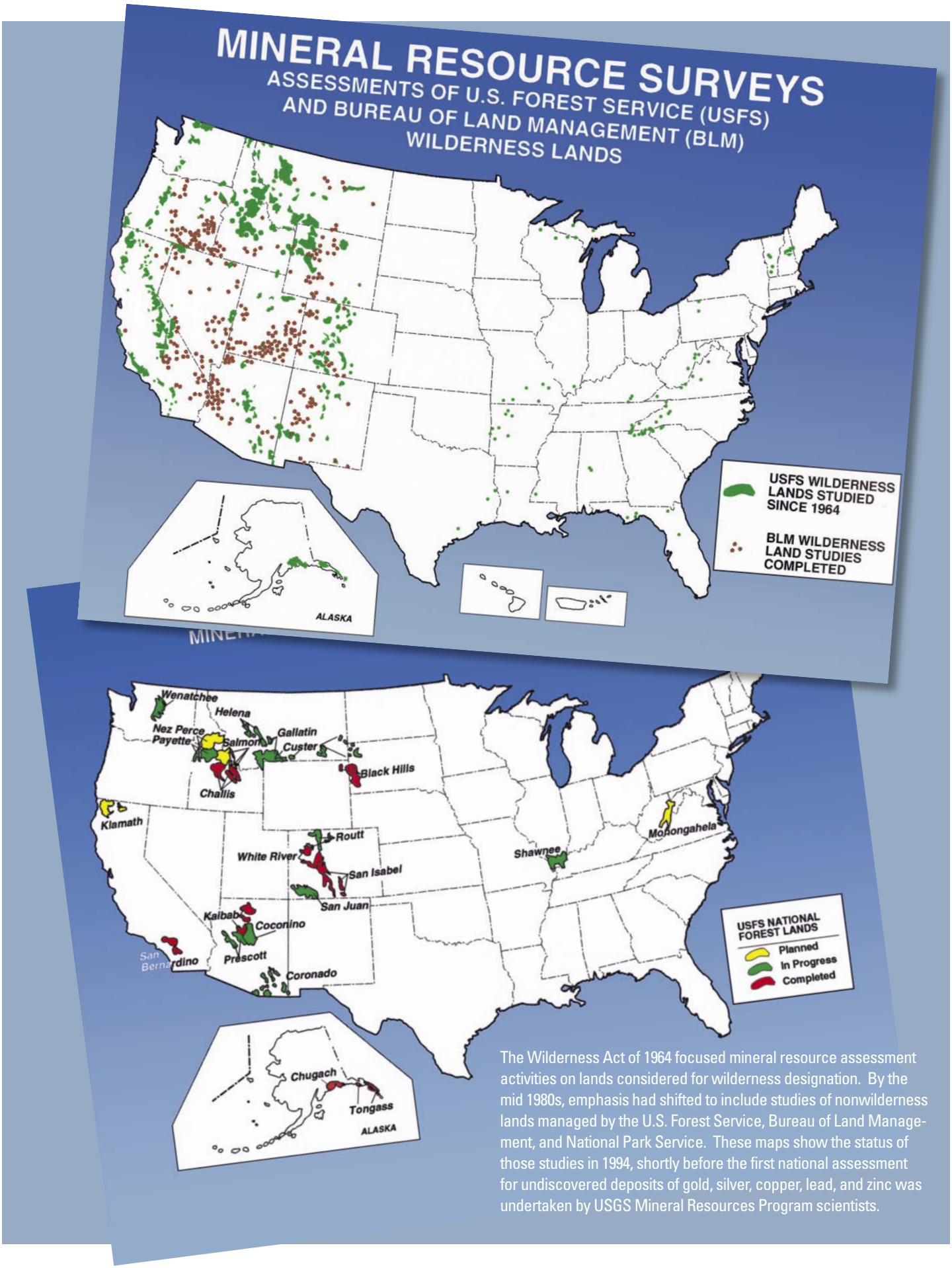
Managing for Multiple Use

In the early1990s, the northern spotted owl was listed as a threatened species in the Pacific Northwest. Designation of the owl's critical habitat areas for protection from development focused national attention on the economic tensions between preserving biological diversity and maintaining multiple uses of Federal lands. The northern spotted owl lives only in old-growth forests and is considered to be an indicator species for the health of old-growth forest ecosystems. Public attention was centered on the economic impacts caused by the restriction of timber sales and harvesting and on the potential economic impacts that would result from anticipated restrictions on mineral exploration.

In response to these issues, U.S. Geological Survey (USGS) mineral resource scientists, in cooperation with colleagues from the Bureau of Mines, conducted an assessment of undiscovered copper deposits on Forest Service lands that were part of the northern spotted owl habitat. The USGS compiled and analyzed geologic, geochemical, and geophysical data and delineated tracts of land that were permissive for the occurrence of undiscovered porphyry copper deposits and provided probabilistic estimates of the number of undiscovered deposits for copper, molybdenum, silver, and gold. This information was used by the Bureau of Mines in their analysis of potential economic impacts. The Department of the Interior's Spotted Owl Economic Assessment Team also incorporated the information in an economic summary designed to aid the Fish and Wildlife Service in drafting boundaries of northern spotted owl critical habitat areas.



Information from a USGS mineral resource assessment was used to help develop management strategies for the endangered northern spotted owl. Inset Photograph by John and Karen Hollingsworth, U.S. Fish and Wildlife Service. Old-growth forest photograph by Nathan Poage, USGS.



The Wilderness Act of 1964 focused mineral resource assessment activities on lands considered for wilderness designation. By the mid 1980s, emphasis had shifted to include studies of nonwilderness lands managed by the U.S. Forest Service, Bureau of Land Management, and National Park Service. These maps show the status of those studies in 1994, shortly before the first national assessment for undiscovered deposits of gold, silver, copper, lead, and zinc was undertaken by USGS Mineral Resources Program scientists.

areas have contributed to the Alaskan economy through the subsequent development of new mines. Discovery of the world-class lead-zinc mine at Red Dog Creek is one important outcome of USGS research and mineral resource assessment activities in Alaska.

The USGS Mineral Resources Program continues to conduct research, collect basic data, and provide new mineral resource assessments for priority areas in Alaska. The Taylor Mountains area, in southwestern Alaska, has been an area of interest to users of mineral resources data in Alaska for many years, despite tremendous logistical difficulties. The Program has ongoing work there, conducted in partnership with the Bureau of Land Management and the Bristol Bay Native Corporation. In recognition of the value of these activities, Congress in 2005 appropriated just over $1 million specifically to support research in Alaskan areas with high mineral resource potential. These funds were used to augment the Taylor Mountains study, and in that one year the area studied was quadrupled. New geologic mapping, geochemical data, and geophysical surveys were conducted and made available to users immediately. These data are being used by the State, the Native Corporation, and the Bureau of Land Management for land planning, and by private industry to explore for new mineral deposits.

Conterminous United States Mineral Assessment Program

The model for resource assessments in Alaska was extended to the lower 48 States in 1977 when the USGS began the Conterminous United States Mineral Assessment Program (CUSMAP). The objective of this multiyear project was to gather, interpret, and disseminate information on nonfuel mineral resources in a systematic manner and on a regional scale that would be helpful for land-use planning and resource management of Federal lands. A series of 1:250,000-scale quadrangles were identified for study and prioritized on the basis of the probable importance of mineral resources in the area, the amount of Federally owned land, the urgency for resource information for Federal land withdrawals or urbanization, and the potential for USGS-State cooperative projects. Supplementary mapping and research continued once data on the geology, geochemistry, geophysics, and mineral deposits of the area were collected.

Environmental Health and Public Safety

Techniques and methods developed in the Mineral Resources Program to support mineral-resource assessments of large areas have also proved valuable for solving geoenvironmental problems. The environment in which mineral deposits occur is a key part of the geoenvironmental condition of an area. In particular, Program research addresses concerns related to thousands of abandoned mines on Federal lands. Scientists supported by the Program have been crucial contributors to interdisciplinary efforts to learn about environmental impacts associated with abandoned mine sites and the processes behind the observed effects. Results of this research, including the techniques developed to identify sources of contamination and the processes that interact to create biogeochemical cycles, are applicable well beyond the boundaries of Federal lands and are of use to land managers both in the United States and abroad.

In the mid to late 20th century, Congress enacted a number of laws that reflected the growing awareness of and concern about environmental contamination, resulting from both naturally occurring mineral deposits and inactive and abandoned mine sites. In the early 1990s, a study near Summitville, Colorado, demonstrated the power of integrating information from many scientific disciplines to help under-

Discovery and Development of the Red Dog Mine, Alaska

In late 1990, after 10 years of exploration and development work, the Red Dog mine in Alaska went into production. As of May 2005, proven and probable reserves were estimated at approximately 85 million tons of ore containing 18.2 percent zinc and 4.6 percent lead. These reserves make Red Dog a world-class deposit and the world's largest producer of zinc concentrate.

As in most major mineral-resource operations, successful development depended on a chain of events, and each event was critical to the discovery and development process. In the early stages, the U.S. Geological Survey (USGS) provided scientific data and information important for understanding the magnitude of the lead and zinc deposit.

The orange- and red-stained creek bed that drains the area around the current Red Dog mine was known to generations of the local Inupiat of northern Alaska, because no fish lived in the mineral-rich waters of the creek. In the late 1960s, during reconnaissance geologic investigations, USGS geologists noted the presence of widespread iron-oxide staining in drainages of the western Brooks Range while flying with pilot and part-time prospector Bob Baker from Kotzebue, Alaska. Samples collected from the creek bed in this remote area were determined to have as much as 10 percent lead—an exceptionally high level. On the basis of these chemical analyses and other observations in the area, USGS geologists recommended the Red Dog Creek area for additional study and exploration (Tailleur, 1970).

As a direct result of the initial USGS data release, both industry and the Bureau of Mines conducted studies that led to discovery of the Red Dog lead-zinc deposit, and the area of Red Dog Creek was excluded from Federal land withdrawals that would have precluded the development and mining of the deposit. In 1978, the NANA Regional Corporation, one of 13 Alaska Native regional corporations, selected the lands containing the Red Dog deposit for conveyance as part of the Alaska Native Claims Settlement Act. NANA entered a joint agreement with Cominco Ltd. to develop the property in 1982.

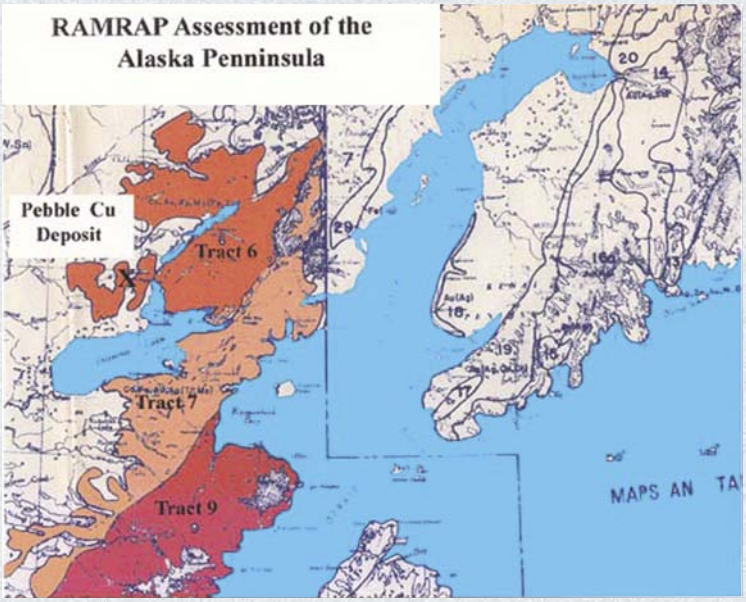
The USGS continues to provide information on the complex factors that controlled formation of mineral resources at the Red Dog mine and at similar deposits elsewhere (Kelley and Jennings, 2004). The resulting mineral deposit model has benefited industry in exploring for similar deposits in Alaska and other areas. The improved mineral deposit model is particularly important in conducting mineral-resource assessments in areas with rocks similar to those of the western Brooks Range.

Open-pit mining operations of the Main deposit (foreground) at the Red Dog mine, Alaska. Mill and accommodation complex are the low white buildings on the far left. View looking west. Photograph by K.D. Kelley, 1998.

Pebble Copper-Gold-Molybdenum Deposit, Alaska

Although Alaska experienced a gold rush in the early 20th century and had been a leading producer of copper in the 1910s and 1920s, the State was not a major supplier of minerals in the 1970s when Alaska public lands were being classified for use. Legislation regarding land-use decisions for 375 million acres of land was pending in the years 1974-78, when the U.S. Geological Survey (USGS) undertook an assessment of the undiscovered metallic mineral resources in Alaska. Comparison of Alaska to geologically similar regions of comparable size led many to believe that there were important undiscovered mineral resources. However, when the USGS regional mineral resource assessment began, large regions had not been geologically mapped, geochemical and geophysical surveys were far from complete, and nothing was known about the mineral potential in much of the State (Singer and Ovenshine, 1978).

The first State-wide mineral resource assessment of undiscovered metallic mineral resources in Alaska was published by the USGS in 1978, and it identified numerous tracts as having potential for undiscovered mineral resources. One area of note in southwest Alaska was identified as having "a 90 percent chance of at least 1 or more, a 50 percent chance of 3 or more, and a 10 percent chance of 8 or more undiscovered porphyry copper deposits" (MacKevett and others, 1978, table 2, tract 6). Exploration undertaken by Cominco in the 1990s and subsequent work by Northern Dynasty Minerals, Inc. led to discovery of the Pebble deposit, which is said to be "the largest deposit of contained gold resources in North America….. and the second largest deposit of contained copper resources in North America" (Northern Dynasty Minerals, 2005). In addition, a number of other prospects in the area have been identified and partially explored, and there is every indication that there will be further exploration and development. The new concepts and methods that were first developed in the USGS Mineral Resources Program during the early 1970s, and refined continuously since, have proven to be applicable not only in Alaska but also in other areas, especially in the western United States, where mineral resource assessments were needed to help make land-use decisions.



The USGS regional Alaska Mineral Resource Assessment Project (RAMRAP) identified Tract 6 as an area with a 90 percent chance of having one or more undiscovered deposit of porphyry copper (Singer and Ovenshine, 1978, sheet 2). The area has since been identified as the largest deposit of contained gold resources and the second largest deposit of contained copper in North America. From Menzie and others, 2005.

stand a regional problem related to inactive and abandoned mines. The Alamosa River, which runs through the San Luis Valley in southwestern Colorado, is a source of water used extensively for irrigation and domestic purposes, and it is the water supply for the Alamosa National Wildlife Refuge and nearby wetlands. Increased concentrations of heavy metals and acid in the river water were attributed to the Summitville mine, which had been abandoned in December 1992. The contamination problem, compounded by erosion of unmined but highly mineralized rocks in the San Juan Mountains, focused national attention on environmental effects that can result from mineral resource development. Federal, State, and local agencies, along with Alamosa River water users and private companies, began extensive studies at the mine and in surrounding areas to determine the primary sources of contamination and their effects downstream from the mine.

The USGS provided geologic and hydrologic information about the Summitville mine and surrounding area and described and evaluated the environmental condition of the mine and its downstream effects on the San Luis Valley. Studies of the 1993 alfalfa and barley crops showed metal concentrations in crops irrigated with water affected by acid mine drainage from Summitville were far below toxic levels and were well within concentration ranges measured in alfalfa and barley crops elsewhere in the United States. In fact, local farmers believed the increased copper levels measured in alfalfa crops actually increased the crops' value because copper is an essential nutrient for cattle and is typically added to cattle feed. USGS studies helped to avert a crop and food scare that could have cost farmers in the San Luis Valley a substantial amount of lost revenue. Learning about the geologic and hydrologic history of the area was a critical part of understanding the environmental effects of mining at Summitville (King, 1995).

The Biogeochemical Cycle

Three principal ingredients make up the biogeochemical cycle. (1) Source of chemical elements (where do they come from?). The source determines how elements are physically and chemically distributed and to what extent they are available within the cycle. (2) Transport mechanisms (how do elements move through the environment?). Commonly, these mechanisms include water, wind, gravity, and living organisms and are heavily influenced by climate. (3) Sites (fate) of deposition (where and why does transport stop?). For example, the elements may be deposited as a part of the sediment in a reservoir or they may be taken up by a plant and perhaps become part of the food chain. Not all deposition sites are permanent, and chemical elements can be remobilized if physical or chemical conditions change.

—King, 1995, p. 5

Digital Data Sets and Maps for Land Managers

Data collection has been a critical part of every mineral resource assessment. The uses of these data extend beyond preparation of the assessment and beyond the USGS. Basic descriptive data are some of the most requested products of mineral resources research and assessments. For many years, any request for original data was answered with reams of paper, then in the 1970s and 1980s by data on magnetic tapes and floppy discs. The 1990s saw a rapid evolution of powerful techniques for management, visualization, and dissemination of large data sets that revolutionized how data are represented, and the widespread development of the World Wide Web has revolutionized how data are made available to others.

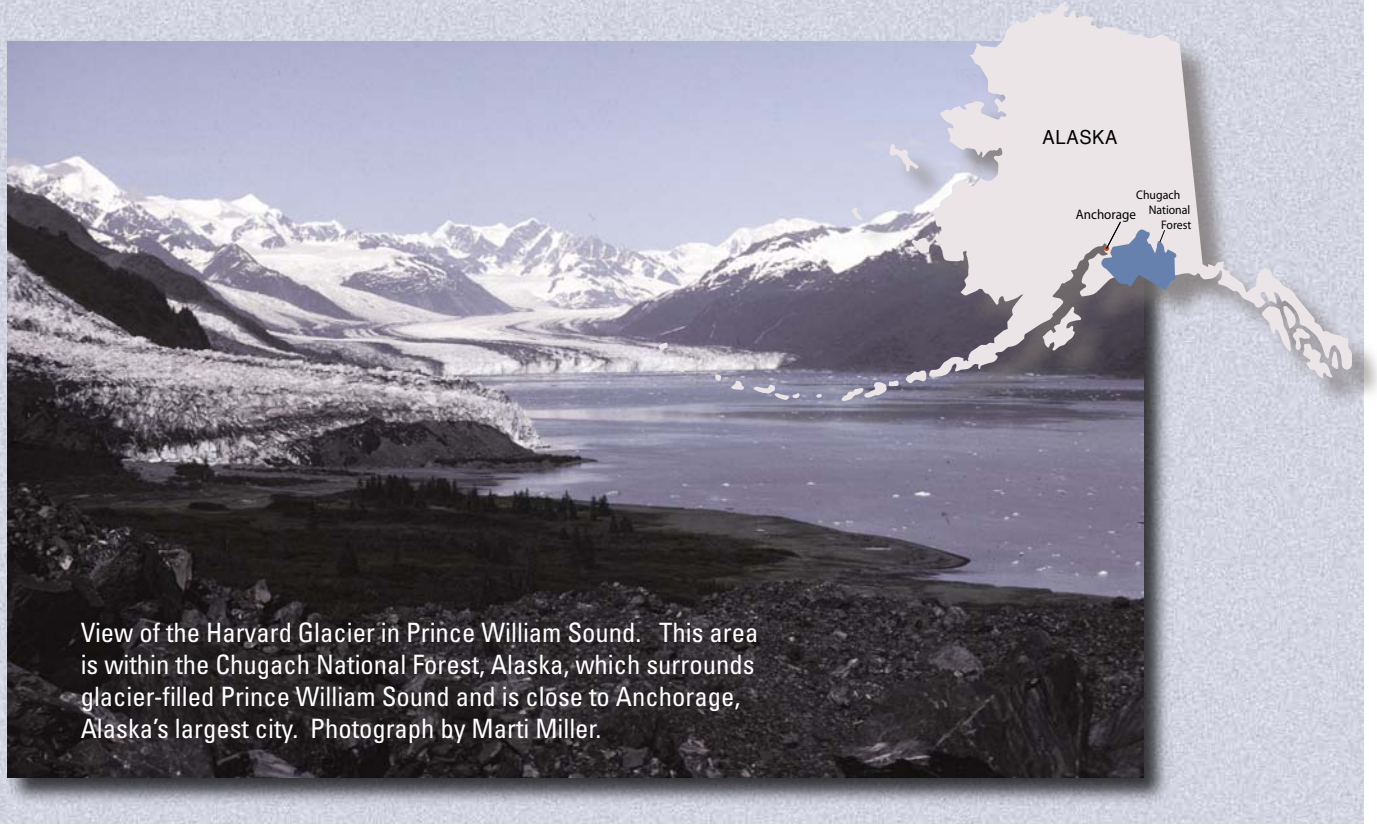
Increasing reliance on descriptive and quantitative geospatial data led the Mineral Resources Program to invest in data conversion and standardization and in development of Internet-based data delivery tools. High-quality digital data and information can now be delivered directly to partners in land management and other government agencies, private industry, and academia. As these tools become more sophisticated, and as the Program's partners and customers are better able to access information when and where they require it, USGS research results are increasingly useful to a widening audience.

The Program is currently completing a long-term project to develop national digital data sets for geology, mineral deposits, geochemistry, and geophysics using data collected over many years. These data sets will continue to grow with the addition of information from new studies. The data sets allow users, both within and outside the Program, to customize information for their individual needs, whether those be assessments of mineral resource potential, determination of regional background values for chemical elements, characterization of regional mineral districts, or identification of relationships among potentially toxic commodities, mining practices, and human health.

Mineral Studies in the Chugach National Forest, Alaska

The Chugach National Forest, the second largest forest in the National Forest system, was created in 1892 by presidential proclamation as the Afognak Forest and Fish Culture Reserve. The 5.5-million-acre Forest is located in south-central Alaska and forms a great arc around Prince William Sound on the Gulf of Alaska. The Forest is known as an outstanding fish and wildlife habitat that provides world-class recreation and tourism opportunities. It also has a long history of mineral resource activity. Gold was first discovered in the area by a Russian surveyor in 1848, and copper was mined intermittently between 1897 and the late 1930s. The Forest has been the subject of numerous government mineral resource studies extending back to the early part of the 20th century. In the 1970s, the western part of the Forest was studied as part of the Alaska Mineral Resource Assessment Program (AMRAP). In the 1980s, a broader regional study of the entire Forest was conducted under provisions for mineral resource surveys as outlined in the 1964 Wilderness Act (Nelson and Miller, 2000).

In 1990, U.S. Geological Survey (USGS) scientists were asked to conduct a mineral resource assessment of undiscovered resources as part of the Forest planning process of 1991-1996. When the Forest Plan was revised in the late 1990s, the Forest managers requested that the USGS conduct an additional assessment of mineral resource tracts outlined in the previous study. A report by Nelson and Miller (2000) provided mineral resource information to guide the forest managers in formulation of the Chugach Land Use Management Plan and in support of Landscape Analysis reports prepared for future site-specific analyses and planning. The Forest Supervisor reports the work by Nelson and Miller "was key to identifying areas that held a high potential for mineral development and was pivotal in the designation of prescriptions across the forest …. and supports land use decisions made in the Forest Plan" (J.L. Meade, Forest Supervisor, written commun., 2005).



View of the Harvard Glacier in Prince William Sound. This area is within the Chugach National Forest, Alaska, which surrounds glacier-filled Prince William Sound and is close to Anchorage, Alaska's largest city. Photograph by Marti Miller.

Case Study: Interior Columbia Basin Ecosystem Management Project

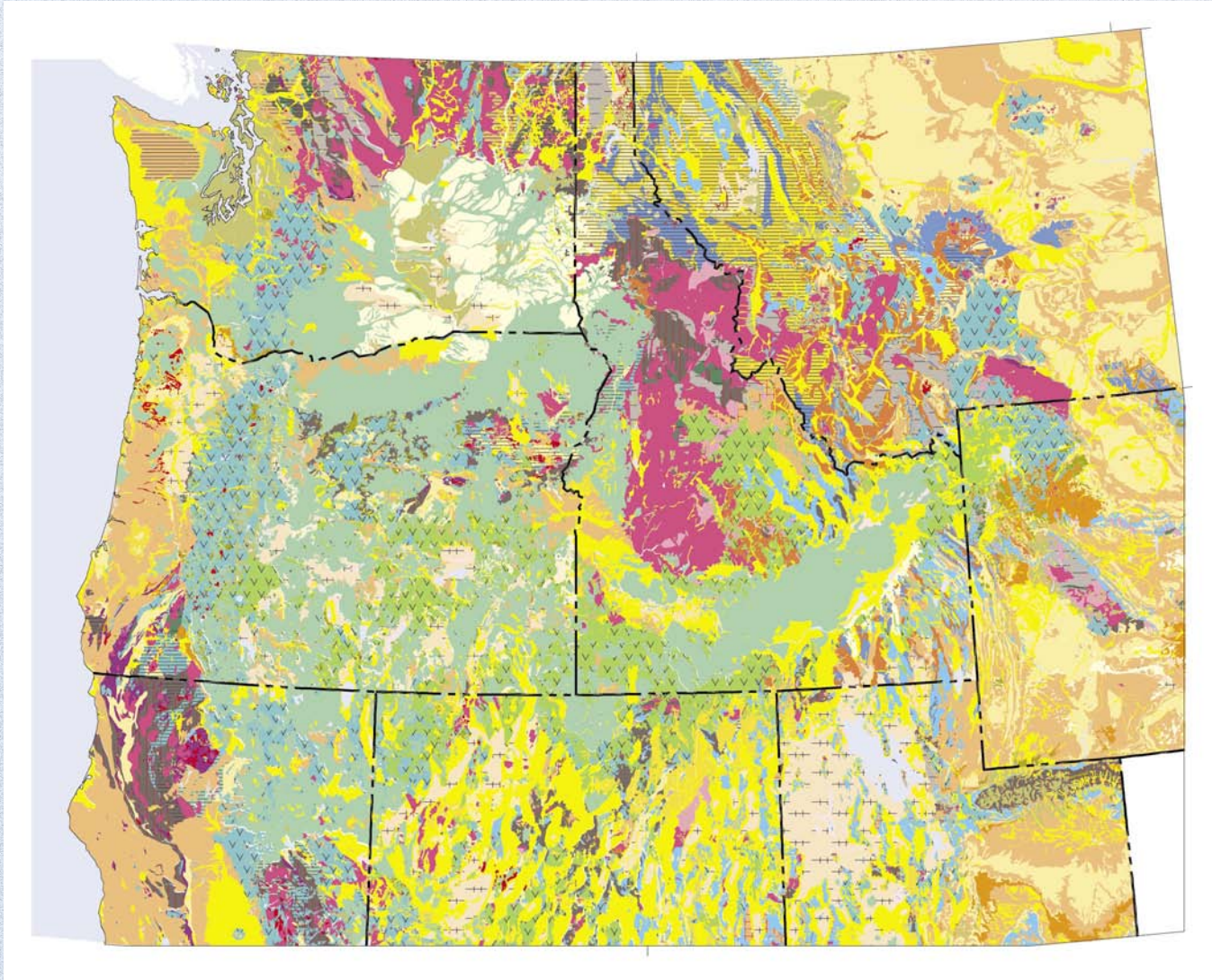
In 1993, the interagency Interior Columbia Basin Ecosystem Management Project was initiated by President Clinton. The project was designed to develop a scientifically sound, ecosystem-based strategy for managing 64 million acres of land administered by the Forest Service and the Bureau of Land Management within the Columbia River Basin and portions of the Klamath River Basin and Great Basin in Oregon (Interior Columbia Basin Ecosystem Management Project Web site, www.icbemp.gov). From the beginning of the planning process, U.S. Geological Survey (USGS) scientists worked closely with land managers to create research products targeted to the needs of the decisionmakers.

Project designers wanted to increase understanding of the interrelationships among the ecological, biophysical, social, and economic conditions, trends, risks, and opportunities within the planning area. Creation of the project was driven by a wide range of concerns, including forest and rangeland health, uncharacteristically intense wildfires, endangerment of selected fish and wildlife species, and concerns about social and economic well being of local communities.

USGS Mineral Resources Program scientists used the project to demonstrate how data collected as part of a mineral resource assessment could be tailored to specific needs of land managers using new digital mapping programs. A massive digital map compilation by Johnson and Raines (2001), showing bedrock geology of the Pacific Northwest, resulted in a map with more than 800 geologic units. Because the data were digital, geologists were able to produce derivative maps that combined rock units by age, as traditionally shown on geologic maps, and also by rock type. The derivative maps have proved useful to a variety of land managers. For example, scientists studying the aquatic biology of the area found that combining the geologic map units according to physical or chemical characteristics, such as degree of consolidation and aluminosilicate content, facilitated identification of aquatic habitat for bull trout and cutthroat trout. Researchers affiliated with the Intermountain Forest Tree Nutrition Cooperative, a research cooperative of public and private forestry organizations, used derivative maps in which units were classified on the basis of elemental and chemical compositions of the rock units (base metals, iron-magnesium-aluminum, phosphate, carbonate, and potassium); their work shows a strong association between poor forest health and low-potassium bedrock, a finding that will be useful in planning plantings.

The Interior Columbia Basin Ecosystem Management Project was one of the first studies to take advantage of evolving digital technology to manipulate large datasets. The ability to combine data of different types enhances understanding of both the geology and the ecosystem and supports decisions about threatened and endangered species, as well as future mineral exploration and development.

Techniques pioneered in this project set a standard for delivering mineral resource information that better meets the needs of planners addressing today's complex issues. Many of the techniques pioneered in the project were employed in the response to a request from the Forest Service in the late 1990s for geologic information for the Northern Rocky Mountains of Montana, Idaho, and Washington. When the preliminary products were reviewed, Forest Service Manager Jim Shelden summed up the benefits of being able to access the digital information when he said "problems, needs, and tasks can be evaluated in light of the data, potential courses of action rapidly evaluated, a plan formulated, and products delivered much more rapidly" (Jim Shelden, USDA Forest Service, written commun., 2005).



The preliminary map of major bedrock types of the Interior Columbia Basin Ecosystem Management Project area shows 38 general map units, summarized from a large geologic dataset of more than 800 map units (Johnson and Raines, 2001). On the map, major features are highlighted by color. Red identifies the giant Idaho Batholith and other intrusive igneous bodies; the extensive volcanic terrains appear in green. Carbonate rocks show as blue, clastic sedimentary rocks as brown or tan. Yellows indicate areas where bedrock is buried under unconsolidated surficial deposits. The grouping of map units according to physical or chemical characteristics proved very useful to managers charged with making land use decisions.

A new effort is underway to build on an existing data set of background concentrations of metals and other trace elements in soils of the conterminous United States. The limited data set of 1,323 samples, collected during the 1960s and 1970s by the USGS (Boerngen and Shacklette, 1981; Shacklette and Boerngen, 1984) is currently the most frequently requested data set managed by the Program. In cooperation with other state and Federal agencies and colleagues in academia, new soil samples are being collected that will demonstrate variations in soil geochemistry across the United States. Research conducted in parallel with the new sampling will contribute to an increased understanding of how organisms concentrate metals and of how the presence of specific organisms or suites of organisms can be used as indicators of processes occurring in soils. An understanding of the baseline of the current elemental composition of our soils is critical to recognizing and understanding any future changes due to natural events, such as volcanic eruptions, hurricanes, wildfires, or dust storms, or human activities such as industrialization, urbanization, waste disposal, agriculture, or mining. Geochemical studies of soil samples will help to address questions raised by land-management and regulatory agencies about what is currently in our soils and how these constituents may impact our lives, and they will help establish realistic expectations for remediation of contaminated soils.

International Studies

The distribution of mineral resources is not limited by national boundaries. Neither is the need for information about them. Since at least the time of World War II, the USGS Mineral Resources Program has responded to requests that support U.S. national interests by providing worldwide assistance to other Federal agencies, including the Department of Defense, the U.S. Agency for International Development, and the U.S. Trade and Development Program, as well as directly to foreign clients. Products have included training and technology transfer, mineral resource and geoenvironmental assessments, and basic mineral deposit research. The techniques of mineral resource assessment are applicable worldwide, and USGS scientists participating in international cooperative activities have trained local geologists in modern techniques in many parts of the world, particularly in Latin America and Asia. These studies have contributed both to economic development in those countries and to the worldwide information base that the USGS provides for our government.

In 1944, the first USGS employee arrived in the Kingdom of Saudi Arabia in response to a request to President Franklin D. Roosevelt from King Abdul'aziz ibn Sa'ud for technical expertise to advise him on the Kingdom's natural resources. The USGS maintained a presence there until 2003. Scientific studies included the geology, mineral resources, water resources, and seismicity of the Arabian Peninsula. Over the years, Mineral Resource Program scientists trained and mentored many Saudis in a wide range of jobs, contributed significantly to the geologic knowledge base of their country, identified numerous mineral deposits, and helped create the Saudi Geological Survey.

In 1985-86, a project funded by the U.S. Agency for International Development called for a mineral resource assessment of the Republic of Costa Rica. Program scientists worked with colleagues in the Dirección General de Geología, Minas, e Hidrocarburos and the Universidad de Costa Rica to produce the assessment, which included the first geologic map of the entire country and a digital catalog of all known mineral deposits in the country. Up until that time, the international mining community had paid little attention to Costa Rica. The USGS study, which identified areas with potential for deposits of gold, copper, manganese, and aluminum, called attention to the possibilities for mineral development. Subsequent to release of the study, a small but energetic mining industry has evolved, and the investment of

Impartial Assessment of Mining-Related Environmental Issues on Marinduque Island, Republic of the Philippines

At the request of the Republic of the Philippines, U.S. Geological Survey (USGS) scientists led an interagency team from the United States to assess mining-related environmental problems, including potential health effects and mine safety issues at Marinduque Island. Over several decades, open-pit copper mining at two different sites has resulted in release of large volumes of tailings, mine wastes, and acid mine waters into rivers and nearshore marine environments. In 2002, work was begun to collect new data on water quality, soil and tailings chemistry, and aquatic ecology, that enabled team scientists to prioritize mining-related issues that posed the greatest risk to public safety, the environment, and human health. They also were able to assess relative strengths and weaknesses of potential options for remediation.

The available data suggest that a variety of human health problems (such as elevated levels of lead in blood) in some island residents cannot conclusively be linked to mining activities, as previously believed. The team provided recommendations for further environmental monitoring and extensive health assessment studies needed to more accurately understand the extent and nature of mining-related impacts on the environment and human health. The Philippines government has requested that the work begun on Marinduque Island continue and that a plan be developed for integrating existing geologic data and maps of the entire country in a digital format in preparation for a state-of-the-art mineral resource assessment of the Republic of the Philippines.

Photographic panorama showing erosion of mine waste dumps into the lower Makulapnit siltation impoundment pond on Marinduque Island, Philippines. Digital composite of three photographs by H. Miller and J. Madsen, taken in June 2003.

outside capital has brought modern exploration and mining methods to Costa Rica. Officials in the Costa Rican government have also used the assessment to make land use decisions about which areas of the country are appropriate for environmentally responsible mining and which areas are better reserved from development.

The USGS already had a long history of cooperative activity in Bolivia when, in 1990, the U.S. Trade and Development Program requested assistance in efforts to promote redevelopment of the Bolivian mining industry, which had languished in the years since nationalization of the industry in the 1950s. Bolivia is a country with a long mining industry and was a global leader in silver production in the 16th and 17th centuries and in tin production in the 20th century. Working with the Servicio Geológico de Bolivia, USGS scientists conducted a 2-year-long mineral resource assessment of the western part of the country, the high altiplano and western cordillera. Significant contributions of this study include a comprehensive catalog of the known mineral deposits and districts of western Bolivia and digital geologic maps. In addition, the study identified areas with potential for new discoveries of precious metals and copper, providing a valuable synthesis that is useful for mineral exploration in this part of Bolivia. Program scientists also participated in a concurrent program funded by the InterAmerican Development Bank designed to illuminate the processes responsible for gold and silver deposits in the central Andes, and to train local mineral resource scientists in Chile, Bolivia, and Peru in mineral resource assessment techniques developed by the USGS.

Growing demand for information on the global mineral resource base led Program scientists to organize a cooperative international project in 2002, designed to assess the world's undiscovered nonfuel mineral resources. Although global shortages of most nonfuel mineral resources are not expected in the near future, the growing demand worldwide and the amount of time required for development of mineral resources requires continued exploration for and development of resources. The goal of this long-term project is to provide a consistent, comprehensive level of mineral resource information and analysis at continental and global scales. The first three commodities to be assessed are copper, which has important electronic and industrial applications; platinum-group metals, which are critical as catalysts in the automobile, chemical, and petroleum industries; and potash, an indispensable constituent of fertilizer required for food production. Results of this study will be used by a wide range of users, including those involved in land-use management, those involved in the development of economic policy decisions, and those involved in mineral exploration. Working with geoscientists from more than 40 geological surveys and cooperating organizations, the project has strengthened cooperation and collaboration between the USGS and other geological surveys and earth science organizations around the world.

Conclusion

Nonfuel minerals are important building blocks that helped to create our Nation and continue to support our economy today. The U.S. Geological Survey (USGS) continues to provide the minerals research and information necessary for a strong and secure future. USGS responsibility for minerals research and information has continuously evolved since the USGS was established in 1879. This evolution is a result of continuing changes in the Nation's political and social environment as well as advances in science and technology. Expertise developed in earlier eras to support the search for mineral resources today underpins essential studies related to public health by providing systematic information on composition of earth materials. The USGS Mineral Resources Program will continue to build on current and new minerals information and on results of new mineral resource research to respond to issues that will face the Nation throughout this century and beyond.

Acknowledgments

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