MBMG

Montana Bureau of Mines and Geology

Biennial Report of Activities and Programs

July 1, 2012 to June 30, 2014

Photo by Bette Wasik, MBMG

A department of Montana Tech of The University of Montana

DIRECTOR'S INTRODUCTION

Photo by Lisa Wareham

The Montana Bureau of Mines and Geology biennial report is our opportunity to reflect on the many and varied achievements of a unique group of scientists, engineers, staff, and students. As a non-regulatory State agency within the Montana University System, we serve as Montana's geologic survey, addressing topics ranging from earthquake monitoring and geologic mapping to energy development and groundwater.

In this past biennium the MBMG continued efforts to expand our capacity to capture, store, and deliver data and information in various digital formats. Development of our new geodatabase, providing geologic map data for use by geologists for exploration, planning, and economic development, has progressed well: most of our 1:100,000 geologic maps are now available for direct download. These data are also delivered conjointly with our groundwater and surface-water data as well as specialized information (LiDAR, thermal imagery, etc.) for specific projects.

Our GWIC database continues to provide millions of records of well construction, lithology, and chemistry each year; we added more than 3,000 new registered users and now have records for more than 244,000 wells and boreholes. The MBMG increased its publications again this biennium too: we published 66 new maps/reports and provided more than 277,000 files for direct download through our publication website, an increase of about 40,000 files. Our publications are not just about quantity and ease of access; the quality of our work is also noteworthy. Our 2012 publication Information Pamphlet 6, "Coalbed Methane Basics: Ten years of lessons from the Powder River Basin, Montana," by Elizabeth Meredith, John Wheaton, and Shawn Kuzara earned the 2014 John C. Frye Memorial Award from the Association of American State Geologists and the Geological Society of America.

A relatively new addition to our many digital repositories is the Geologic and Mine Data Preservation database. Using special funds from the 2013 Legislature, thousands of unpublished maps, field books, and reports related to mining and geology in Montana are being scanned and catalogued for retrieval. We have received hard copy information from several individuals and State agencies, the Montana Historical Society, and U.S. Forest Service. In addition, these funds were used to preserve and catalogue 488 boxes of rock core samples in cooperation with the Butte–Silver Bow County government.

The MBMG Billings Office has moved from the MSU-Billings Campus to a new building near downtown; our address is now 101 Grand Avenue, Billings, MT. The new facilities will give the public better access to our services and publications as well as more room for student employees from MSU-Billings and Rocky Mountain College.

The MBMG has several new members working on data preservation as well as our traditional areas of research. A complete list of MBMG members is included in this report. Robin McCulloch, Mining Engineer, retired with 24 years of service; Charlotte McKenzie, our Administrative Assistant, retired after 21 years at the MBMG and Montana Tech; and our Laboratory Chief, Steve McGrath, retired after 9 years of service.

In Memoriam

The Montana Bureau of Mines and Geology notes with sadness the passing of Dr. Ed Ruppel, the MBMG's Director and State Geologist from 1986 until his retirement in 1991. Those who knew and worked with Ed knew him to be the consummate field geologist and research scientist. He never left a rock unturned, and saw so much southwestern Montana and eastern Idaho geology over his long career that he was awarded the Tobacco Root Geological Society's first award for Excellence in Field Work. Ed's publications on this region are extensive, including geologic maps and other professional reports, many of them MBMG publications. Ed was also committed to maintaining the stature and relevance of the MBMG, a strong and critical trait that probably developed during his many years at the U.S. Geological Survey, and which underpinned both his internal and external management of the organization. Ed believed, fundamentally, in the importance of a State geological survey. He saw very early the opportunity to be involved with the USGS in the launch of the Co-GEOMAP (now STATEMAP) program that, in turn, has underpinned so many of the MBMG's own geologic and hydrogeologic programs. He also saw early the essential role the MBMG must play in understanding and qualifying Montana's groundwater resources. First in to the office each day, and the last to leave, Ed was quiet, confident, appreciative of others' work and service, and always ready to pore over a geologic map or debate a geologic question. Ed, you will be missed and remembered by us all.

UUNO SAHINEN AWARD

The Silver Medallion Award is given annually by the Montana Bureau of Mines and Geology in memory of Mr. Uuno Sahinen, the first full-time Director and State Geologist of the MBMG. The award is presented to those who have achieved long-term significant contributions to the understanding and development of the geologic and groundwater resources of Montana.

The 2013 Uuno Sahinen Silver Medallion Award was presented to Edward T. Ruppel, Ph.D. on May 13, 2013 at the 113th commencement ceremony of Montana Tech. Originally from Fort Morgan, CO, Ed's family moved to Montana where he was raised and attended local schools in Twin Bridges. Ed received his B.A. from the University of Montana in 1948, his M.A. from the University of Wyoming in 1950, his Doctorate at Yale University in 1958, and his Honorary Doctorate from the University of Montana in 1996.

After completing his B.A., Ed was hired as a geologist with the U.S. Geological Survey engaging in both geologic and mineral resources. His early geological research responsibilities included major studies in Yellowstone National Park, east-central Idaho, and southwest Montana. Ed also held the positions of the Deputy Assistant Chief Geologist for the Central Region of the U.S. and then Chief of the Branch of Central Environmental Geology. During this period Ed also served as the Representative of the Chief Geologist of the Rocky Mountain Region. In 1986 Ed retired from his position at the U.S. Geological Survey and accepted the position as Director and State Geologist here at the Montana Bureau of Mines and Geology. During his tenure at the "Bureau, " Ed was a very active participant in establishing the National Co-GeoMap Program 1986. This program has provided funds for critical geologic mapping in Montana for the past 20 years. Ed also directed significant expansion of the MBMG's groundwater programs, including the Ground Water Assessment Program that began in 1991 and continues today.

Although he retired from the MBMG in 1994, Ed continued mapping and publishing—which included field geological research in the Snowcrest Range in southwest Montana, mapping and evaluating mineral resources in the Virginia City area, mapping the geology of the Continental Divide Trail. In his "spare time" he had been researching the Beaverhead meteor impact area for the University of Princeton. Ed was a Certified Professional Geologist with the American Institute of Professional Geologists, a Senior Fellow of the Geological Society of America, a Fellow with the Society of Economic and Geologists, and a member of the Tobacco Root Geological Society, Montana Geological Society, Colorado Geological Society, and the Geological Society of Washington D.C.

The 2014 Uuno Sahinen Silver Medallion Award was presented to Ennis P. Geraghty, Ph.D. on May 17, 2014 at the 114th commencement ceremony of Montana Tech. Ennis is originally from Warrensburg, New York, a small town in the Adirondack Mountains of northern New York. He received his B.A. from Colgate University in 1969, his M.S. from Syracuse University in 1973, and his Doctorate also at Syracuse University in 1978. Both his Master's thesis and Doctoral dissertation involved mapping in the Adirondack Mountains. As it turns out, his work in New York was excellent training for his future work here in Montana. After completing his formal education, Ennis accepted a position as Research Structural Geologist with the New York State Geological Survey in Albany, New York in 1976 where he continued his mapping career. In 1980, Ennis, with his wife Sue, daughter Emily, and son Chris, moved to Colorado where he joined the geology staff of Climax Molybdenum Company. Eight years later, in 1988, Ennis made that all-important move to Montana to join the geology staff at the newly opened Stillwater palladium–platinum (Pd-Pt) mine. Ennis worked his way up from Development Geologist, to Production Geologist, to Chief Geologist—a position he held from 1994 until 2006.

As Chief Geologist, he was in charge of a department of some 27 geologists providing underground Grade and Dilution Control on the J-M Reef palladium-platinum deposit, core-logging interpretation, and ore-reserve definition. In addition, Ennis carried out structural geology research in the Beartooth Mountain Uplift that included discovery of major geologic structures that would affect production at the Stillwater mine. Since about 1997, Ennis has continued his mapping and research of fault geometries along the Beartooth front and their effect on the metal zones (Pd-Pt, Cr, and Ni-Cu) within the Stillwater Complex. This work culminated in publication by the Montana Bureau Mines and Geology of a regional map titled: "Geologic Map of the Stillwater Complex within the Beartooth Mountains Front Laramide Triangle Zone, South-Central Montana." This was a critical contribution to our understanding of geologic processes in the Beartooth Mountains and of ore formation in the Stillwater Complex, and remains a hallmark publication.

At present Ennis continues to work as Senior Project Geologist for Stillwater Mining Company on current expansion projects along the J-M Reef in the Stillwater Complex. He is a member of the Geological Society of America, Society of Economic Geologists, Society of Mining Engineers, Montana Geological Society, Tobacco Root Geological Society, Wyoming Geological Association, and Yellowstone-Bighorn Research Association.

GROUND WATER ASSESSMENT

The Legislature established the Ground Water Assessment Program (85-2-901 et seq.) in 1991 to improve the understanding of Montana's groundwater resources by collecting, interpreting, and disseminating essential groundwater information. This information is vital for making science-based management decisions.

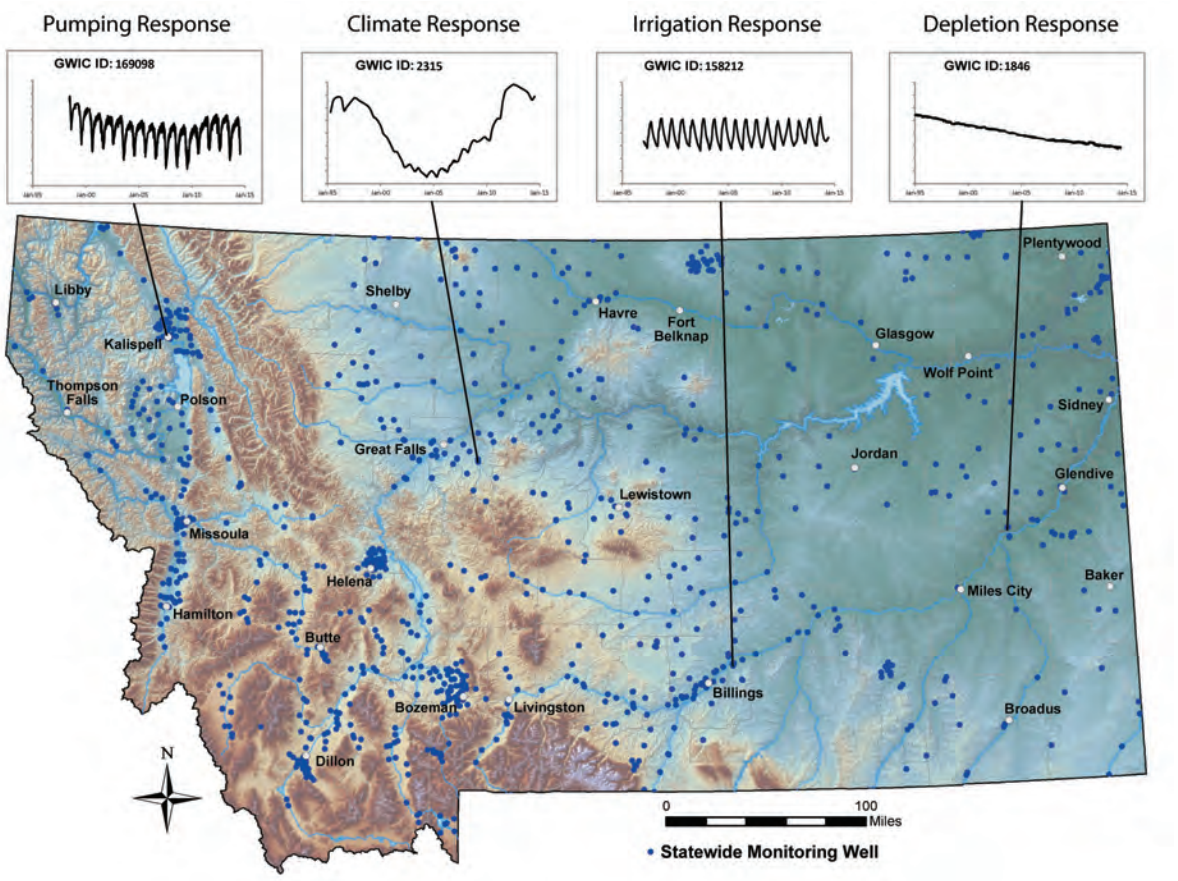
There are three Program components:

- *Groundwater Monitoring*—to produce and maintain long-term water-level and water-quality records,
- *Groundwater Characterization*—to systematically assess and document the hydrogeology and quality of the State's major aquifers, and
- *Groundwater Information Center (GWIC)* database—to make groundwater information widely available.

An interagency Steering Committee selects study areas, coordinates groundwater research among State, Federal, and local government units, and oversees Assessment Program progress.

Ground Water Monitoring

The Ground Water Monitoring Program collects quarterly water-level measurements from strategically located wells across the State. Long-term groundwater-level records are the only direct measure of how Montana's aquifers respond to seasonal, climatic, developmental, or land-use factors. Long-term groundwater hydrographs are similar to long-term records of stream flow and precipitation, and must be evaluated at decadal scales.



Since 1993, the MBMG has been collecting systematic groundwater-level data from a 900+ well statewide network; some wells have been regularly monitored since the 1950s. The network covers the State's major aquifers and includes wells that range from <10 feet to >3,600 feet in depth.

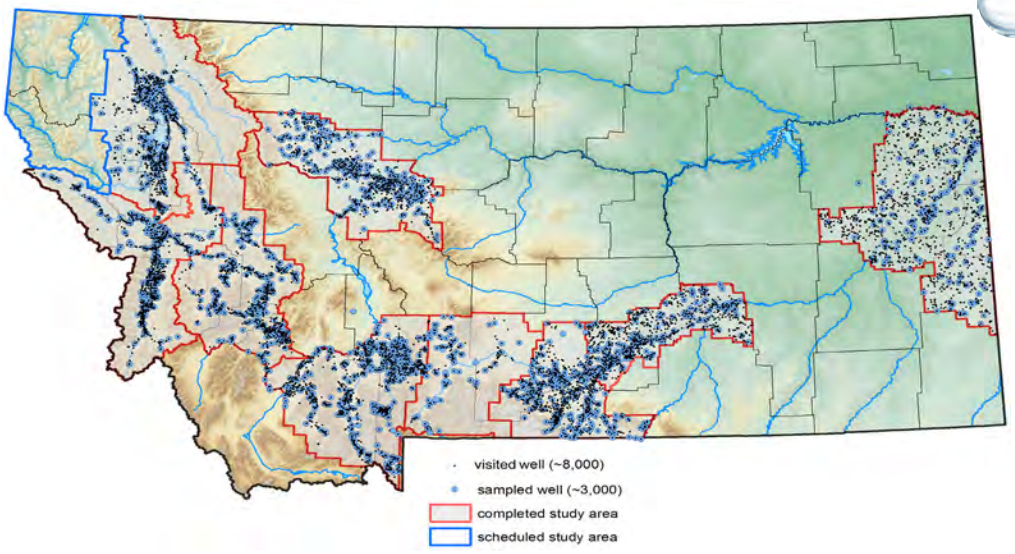
Water levels in many Montana aquifers follow natural seasonal patterns, typically rising each spring and early summer, and declining during the late summer and fall. In addition to the seasonal response, water levels respond to other stresses such as pumping (response may occur in hours or days), climate variability or drought (response may occur in years to decades), and widespread development (response occurs at varying time scales). Montana's long-term network is beginning to show where and which aquifers are impacted by these different stresses, highlighting the value of long-term, decadal-length records. Without continued monitoring, Montanans would have no data about these important issues.

GWIC by the Numbers

- More than 27,289 registered users
- Currently about 3,800 sessions and 38,100 queries each month
- Information on 244,023 wells and boreholes
- Scanned images for 224,991 well log documents
- Results from 61,571 water-quality analyses for 18,051 sites
- 20.1 million water-level measurements

Ground Water Characterization Program

The Characterization Program provides basic information about aquifers within specific areas as prioritized by the Ground Water Assessment Steering Committee. Areas where the Characterization Program has worked, and will work, are shown on the map below.



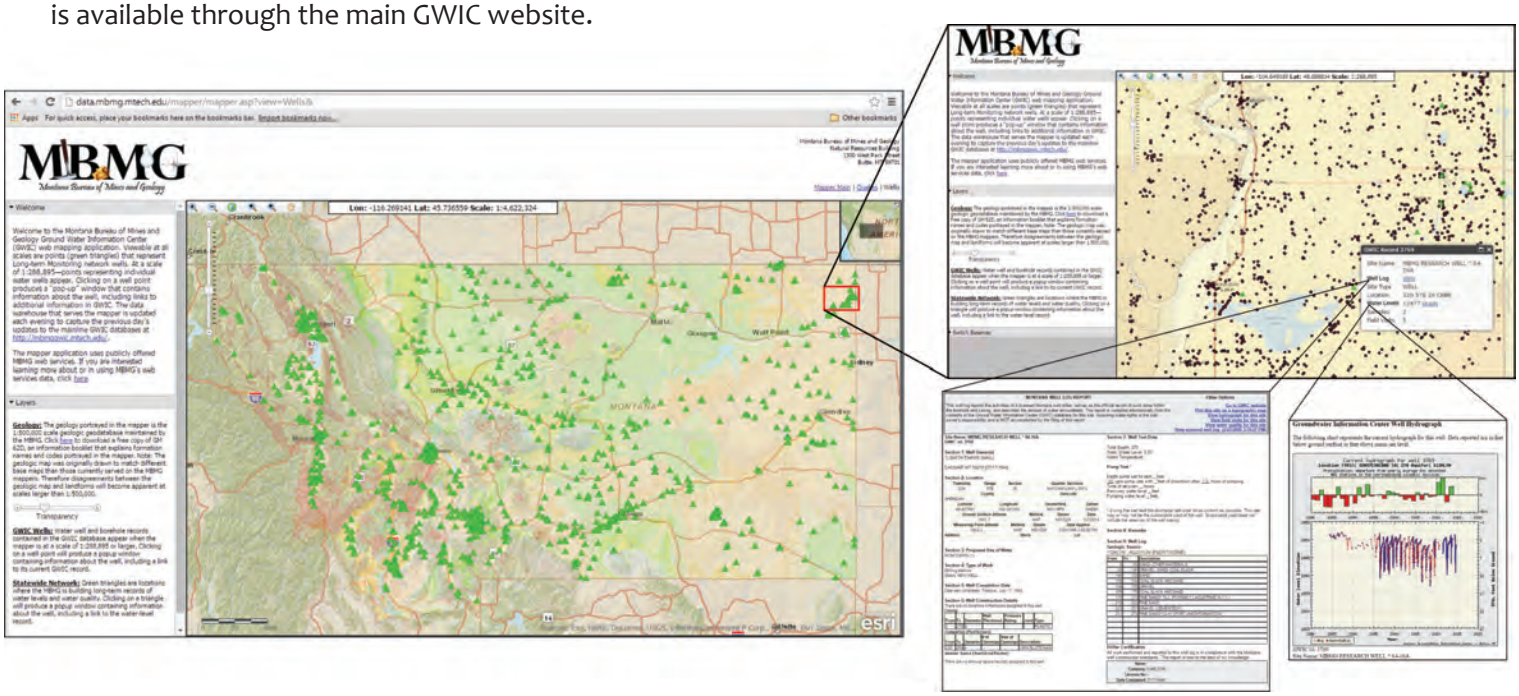
Currently, groundwater data are being collected in Park and Sweet Grass counties, including a collaborative investigation with the Shields Valley Watershed group and the Park County Conservation District to establish baseline water-quality monitoring in areas of potential natural gas development. The Steering Committee has selected the Lincoln–Sanders characterization area for future work.

To date, more than 8,000 wells have been visited and about 3,000 groundwater samples have been collected. These data have been used to compile 60 maps and reports that describe specific aspects of Montana's aquifers, groundwater flow systems, and groundwater quality.

Ground Water Information Center (GWIC)

GWIC customers seek groundwater data generated by MBMG projects, water-well logs, and results from water-quality sampling. GWIC users can choose from 15 report formats to customize data retrievals. During the last biennium GWIC staff continued a 'second pass' through the main body of well logs, scanning and attaching the document images to database records.

GWIC staff have continued to develop innovative ways to access and deliver information. The "Driller Web" tool remains a popular feature with water well drillers; 58 percent of the well logs were submitted electronically during the past 2 years. Also, GWIC staff devised a web mapping application, "Mapper," that interactively delivers water-well and other information using a graphical user interface. Upon activation, the Mapper (below) shows locations of the statewide monitoring network wells and, when zoomed to larger scales, the current locations of water wells. Clicking on a well point will produce a popup window that contains information about the site and links to additional information, such as the well log or a hydrograph. Complete, but non-graphical, access to the full suite of GWIC data is available through the main GWIC website.



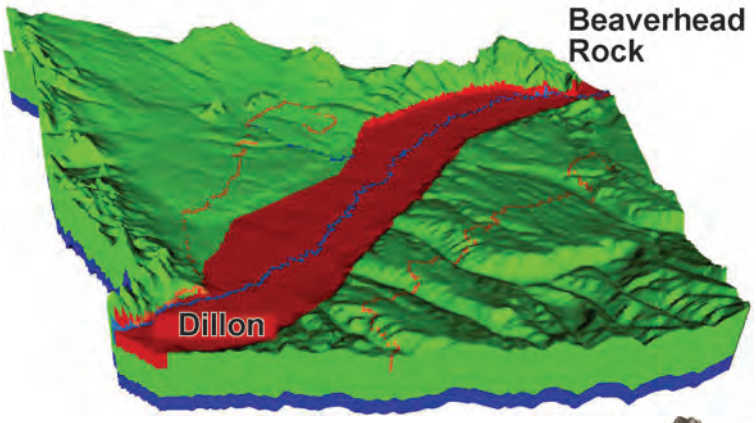
GROUND WATER INVESTIGATION PROGRAM

In Montana, groundwater is essential for safe drinking water supplies and for economic growth. On average, approximately 272,000,000 gallons (835 acre-feet) are extracted from Montana's aquifers every day. In many areas of the State, groundwater is the only reliable year-round source of water for household use and for livestock. Groundwater is also widely used for irrigated agriculture, and for lawns and gardens. In some settings, groundwater withdrawals could directly affect senior water rights holders, stream flows, the availability of irrigation water, and the health of aquatic ecosystems. Efficient water management requires a well-founded understanding of the groundwater systems.

The Ground Water Investigation Program (GWIP) was established by the Montana State Legislature to provide scientific foundations for specific water management challenges.

GWIP in Action

The Ground Water Investigation Program (GWIP), in support of science-based water management in Montana, answers site-specific questions that are prioritized and assigned by the Montana Ground Water Steering Committee, as mandated by the Montana Legislature and authorized in MCA 85-2-525. To meet this goal, GWIP conducts research on specific issues in areas that are ranked as the most urgent within the State.



Detailed hydrogeologic data and land features are represented in a 3-D numerical simulation of the GWIP study area near Dillon. The model was used as a tool to evaluate stresses such as changing rates of groundwater withdrawal on surface water.

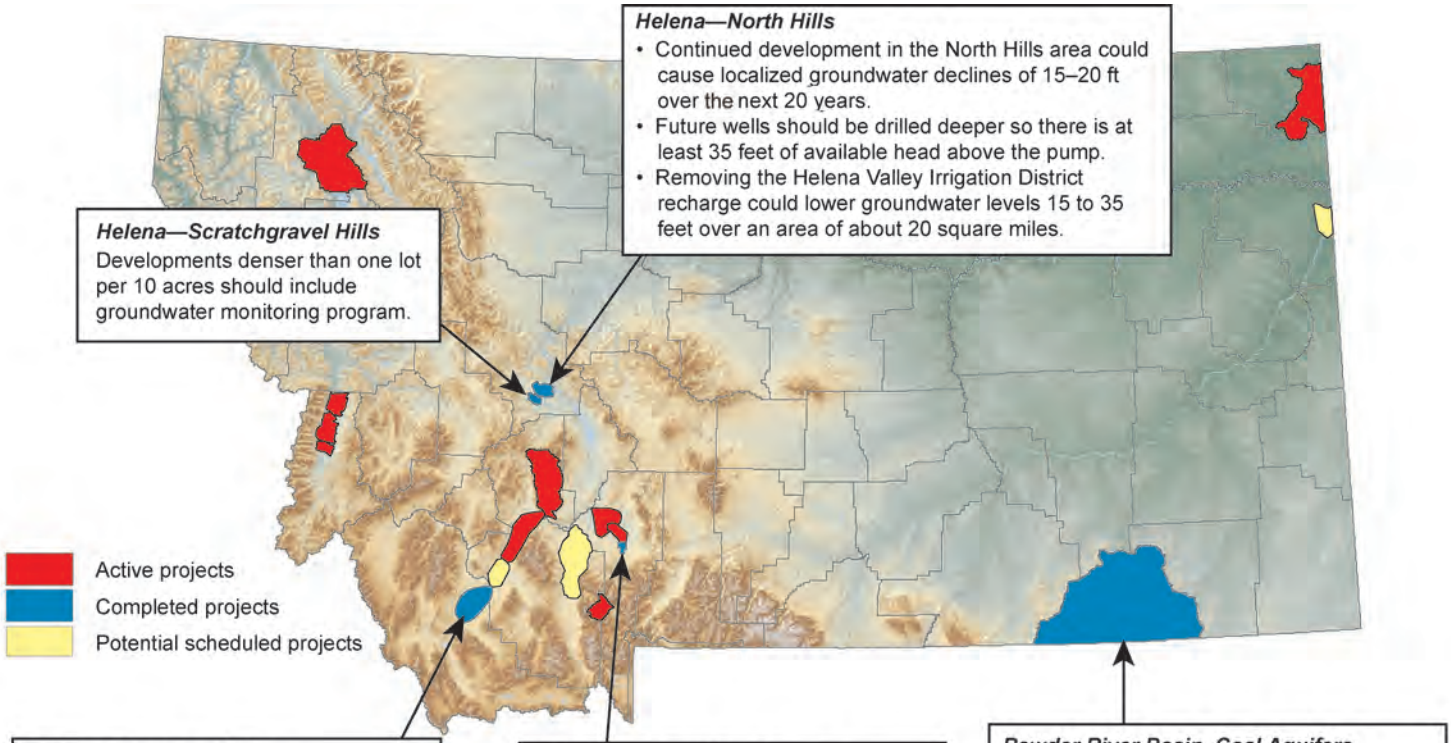
Program Products

Investigations are expected to take from 1 to 3 years to complete.

- Every GWIP investigation will produce a detailed report on the hydrogeologic system, and responses to current and anticipated stresses.
- A comprehensive set of hydrogeologic data are compiled for each site and are permanently available online through the Ground Water Information Center (http://mbmggwic.mtech.edu/).
- In addition, most projects will include a computer model that simulates specific hydrogeologic features and stress responses, and is available online for future test scenarios.

Program Status

To date, over 50 projects have been nominated and prioritized by the Ground Water Steering Committee. Prioritization is based on land-use changes, anticipated growth in housing, agriculture, industry, and commercial activities. Project areas and some results from completed projects are shown below.



Current Research Questions include:

- Aquifer and stream response to changing land use from irrigated agriculture to subdivision.
- Hydrogeologic viability of replacing surface-water diversion points with irrigation wells.
- Groundwater sustainability in response to increasing subdivision demands.
- Changes in water quality due to increasing subdivisions.
- Aquifer sustainability in response to increasing numbers of irrigation wells.
- Viability of developing buried river channel aquifers.
- Impact on stream flow of increasing groundwater withdrawals.

GWIP products are designed to provide a more detailed understanding of the groundwater system and tools that can then be used by regulators, senior water-rights holders, new water-rights applicants, and other stakeholders to make informed water management decisions and to help anticipate hydrogeologic effects from changes in land use.

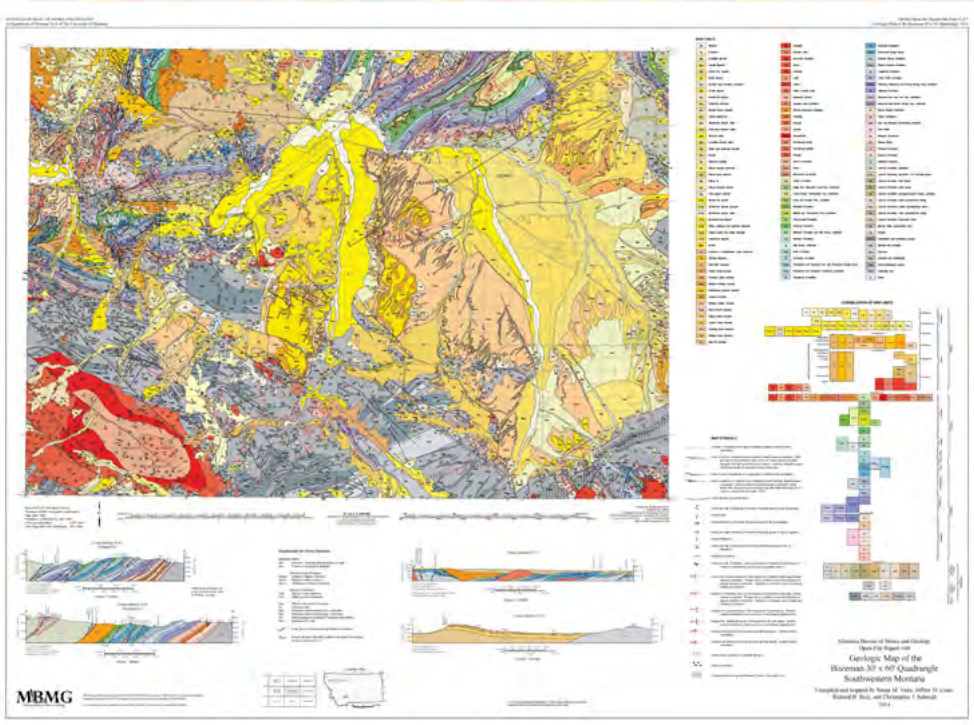
GEOLOGIC MAPPING

STATEMAP and EDMAP

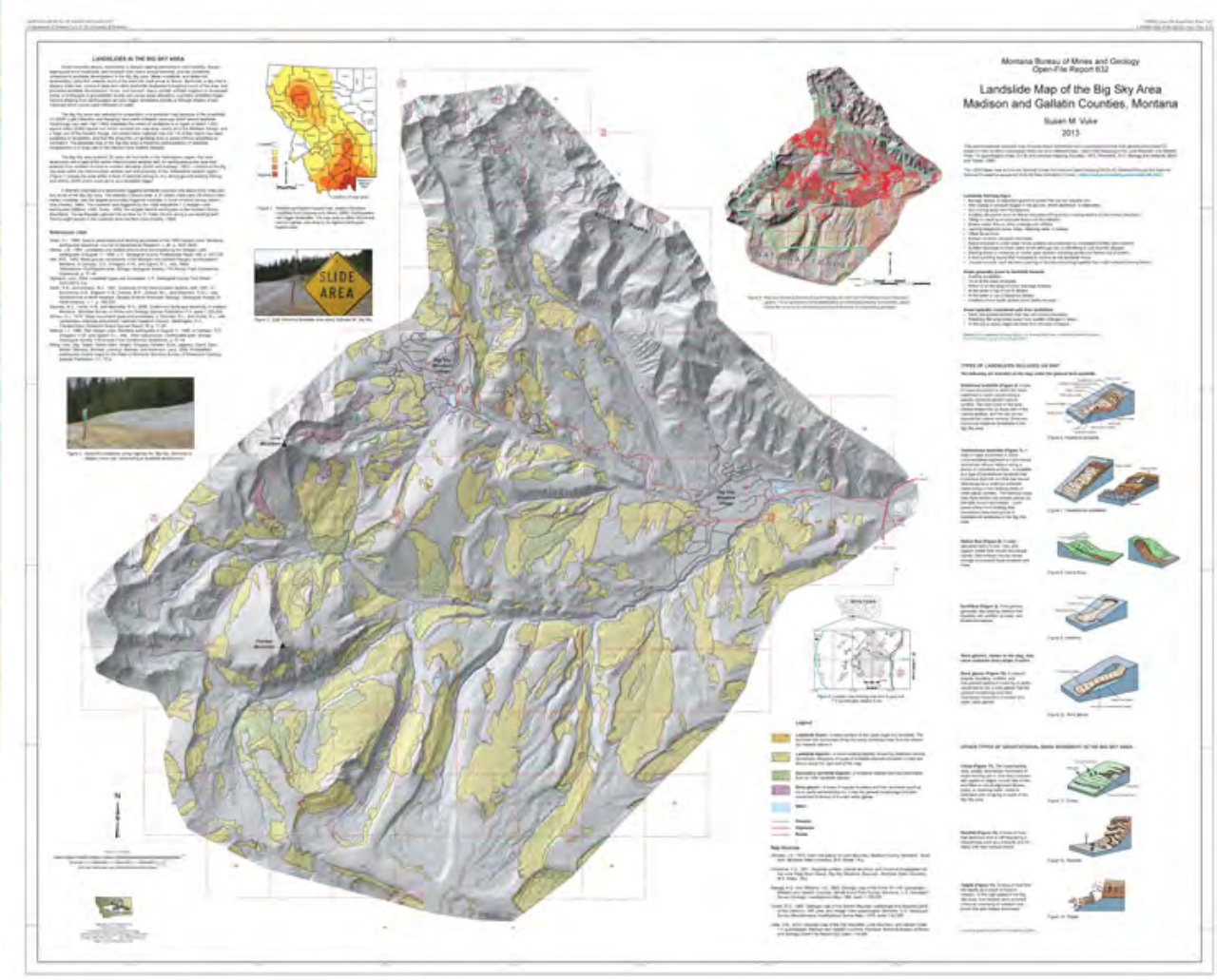
Reliable, detailed geologic information is essential to making good decisions about the complex issues that affect Montana's water, land, and mineral and energy resources. During the past biennium, the Montana Bureau of Mines and Geology published eight new geologic maps based on field mapping conducted through the STATEMAP Program, a component of the National Cooperative Geologic Mapping Program. U.S. Geological Survey funding for STATEMAP is awarded through an annual competitive grant process that requires matching State dollars and completion of all funded maps within one year. Map areas are prioritized by a STATEMAP Advisory Committee composed of representatives from several Montana industries, universities, and Federal, State, and Tribal agencies. The committee's main priority is for the MBMG to eventually complete geologic mapping of the entire State at 1:100,000 scale as 30' x 60' quadrangle geologic maps. The MBMG has completed 1:100,000-scale mapping in eastern and central Montana, so the recent focus is on western Montana. During the past biennium, the Butte South and Dearborn River 30' x 60' quadrangles, and a revised version of the Bozeman 30' x 60' quadrangle, were published. The geologic map of the Salmon 30' x 60' quadrangle was completed and is in preparation for publication. The Elliston 30' x 60' quadrangle is nearing completion, and mapping is underway in the Butte North and Wisdom 30' x 60' quadrangles.

Another priority established by the STATEMAP Advisory Committee is production of larger scale maps that focus on particular geologic issues, transportation corridors, or areas where development is occurring or is anticipated. During the past biennium eight geologic maps of this type were published. They include a geologic map of the Clarkston Valley, where the second largest magnitude historic Montana earthquake occurred, a geologic map that transects the Madison Range from the Madison Valley through Big Sky, and a related landslide map of the Big Sky area. A new, detailed geologic map of the Stillwater Complex was published as well as several maps in the Anaconda and Avon areas. Preparation of many other large-scale maps is underway.

All of the published STATEMAP products are available for free download from the MBMG website.



Bozeman 30' x 60' map, MBMG Open-File 648



Landslide map of Big Sky, MBMG Open-File 632

ENVIRONMENTAL HYDROGEOLOGY: TECHNICAL ASSISTANCE PROGRAMS

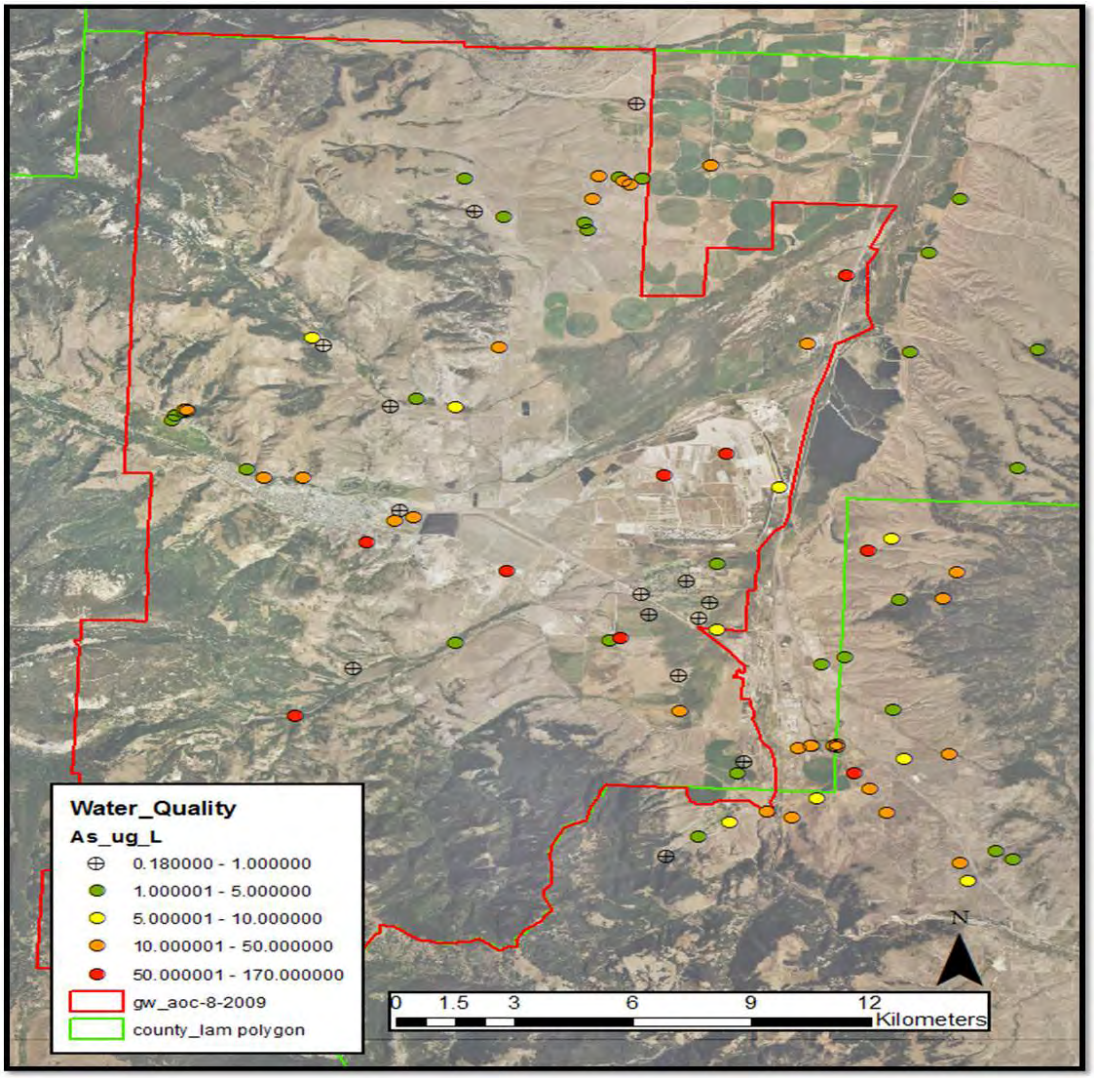
The MBMG works in concert with State and Federal agencies, conservation districts, water-quality districts, and local communities to monitor, identify, and propose solutions to groundwater problems. Current projects run the spectrum from environmental problems associated with historic mining practices to water-quality issues related to organic waste-water chemicals in groundwater and waste-water-system effluent.

Montana has a rich history of natural resource development and corresponding environmental problems associated with those practices. Many of these problems are the result of mining practices dating to the late 1800s and early 1900s, which predate environmental and mining regulations. However, the presence of natural resources that are often the object of mineral extraction can also result in the natural release of harmful elements to State waters. The MBMG has a long history of investigating whether sources of arsenic to the environment are natural or a result of mining activities. In 1989, the MBMG determined that the presence of arsenic in the groundwater of the lower Madison Valley was from diluted geothermal water emanating from Yellowstone National Park and not due to mining-related releases. The MBMG recently completed a study examining the sources of arsenic in the Anaconda area.

Washoe Reduction Works, Anaconda, MT (courtesy of the World Museum of Mining, Butte, MT)

The town of Anaconda, Montana was founded in 1883 for the purpose of constructing a smelter to process copper ore mined in Butte, Montana. Smelting continued in Anaconda until 1980. The smelting location was chosen because of abundant water supplies that didn't exist in the Butte area. Residual arsenic was one of the primary waste byproducts from the smelting process, with large concentrations emitted from the stack in the form of smelter dust. This smelter dust was carried by the winds and distributed across the landscape. As a result, the surface soils near Anaconda have high arsenic concentrations that can leach into the shallow groundwater.

Areas around the Anaconda smelting facilities were placed on the U.S. Environmental Protection Agency's (EPA) National Priorities List (NPL) in 1983. As part of the environmental monitoring of the site, the MBMG has been sampling all private water-supply wells in the area for arsenic. The solution for wells with arsenic concentrations above the drinking-water standard is to drill a deeper well to get below the area influenced by the surface contamination. However, at one location the deeper well (160 meters) had an arsenic concentration nearly three times that of the shallow well (30 meters), which indicated a natural source of arsenic in the area. The recent project evaluated the geochemistry and isotopic signatures of the soils, sediments, rocks, and groundwater in areas with elevated groundwater arsenic concentrations, to determine if natural geologic sources of arsenic could be identified and possibly differentiated from smelter-derived arsenic. It was determined that two areas had natural sources of arsenic that could cause elevated arsenic concentrations in the groundwater, but that the majority of the groundwater arsenic was likely from smelter dust deposited on the soils.



Aerial photo showing groundwater arsenic concentrations near Anaconda.

The MBMG, in collaboration with the Cascade Conservation District, has proposed to continue investigating natural vs mining-related arsenic occurrences in Montana with a 2015 Reclamation and Development Grant Program grant submission. The proposed work will use an approach similar to previous MBMG studies. The focus of the proposed study will be on the occurrence of arsenic in the Madison Aquifer near Great Falls, Montana. Coal mining southeast of Great Falls has caused well-documented acid-mine drainage problems in the area, and it has been speculated that this mining activity may be causing similar problems with groundwater. This study will examine the groundwater and geology of the area to evaluate whether the water-quality issues in domestic wells are a result of mining-related activities or naturally occurring conditions.

Topics Currently Being Investigated

- Acid mine-drainage mitigation through land-use changes and source control at an abandoned underground coal mine, Belt
- Inventory of placer mining operations in western Montana
- Groundwater monitoring of flooding underground mines and the Berkeley Pit
- Long-term monitoring of groundwater associated with the Anaconda Smelter Superfund site
- Assisting with evaluation of restoration options in the Upper Clark Fork River Basin
- Long-term monitoring of chromium concentrations in groundwater at the Mouat chromium repository, Columbus, MT
- Groundwater monitoring at the former Rocker Timber Treating site and review of controlled groundwater area boundary
- Evaluation of arsenic sources in groundwater, Upper Deer Lodge Valley, MT
- Metal concentrations in storm-water runoff, Mill Creek drainage, Anaconda, MT
- Groundwater issues relating to Butte Priority Soils Superfund site
- Crystal and Bullion mine adit discharge monitoring, Jefferson County, MT
- Blacktail Creek bromide tracer study
- Geochemical evaluation of groundwater associated with mine waste, Butte, MT
- Geothermal resource inventory of Montana

ENERGY RESOURCES

A dragline removes overburden and exposes the coal seam at Western Energy's Rosebud Mine near Colstrip, MT.

Coal Availability Studies

With approximately 120 billion tons, Montana leads the nation in demonstrated coal reserves, consistently produces about 4 percent of the nation's supply, and ranks 5th in annual coal production. Five surface mines and 1 underground mine produced about 42 million short tons in 2011 and 45 million short tons in 2010.

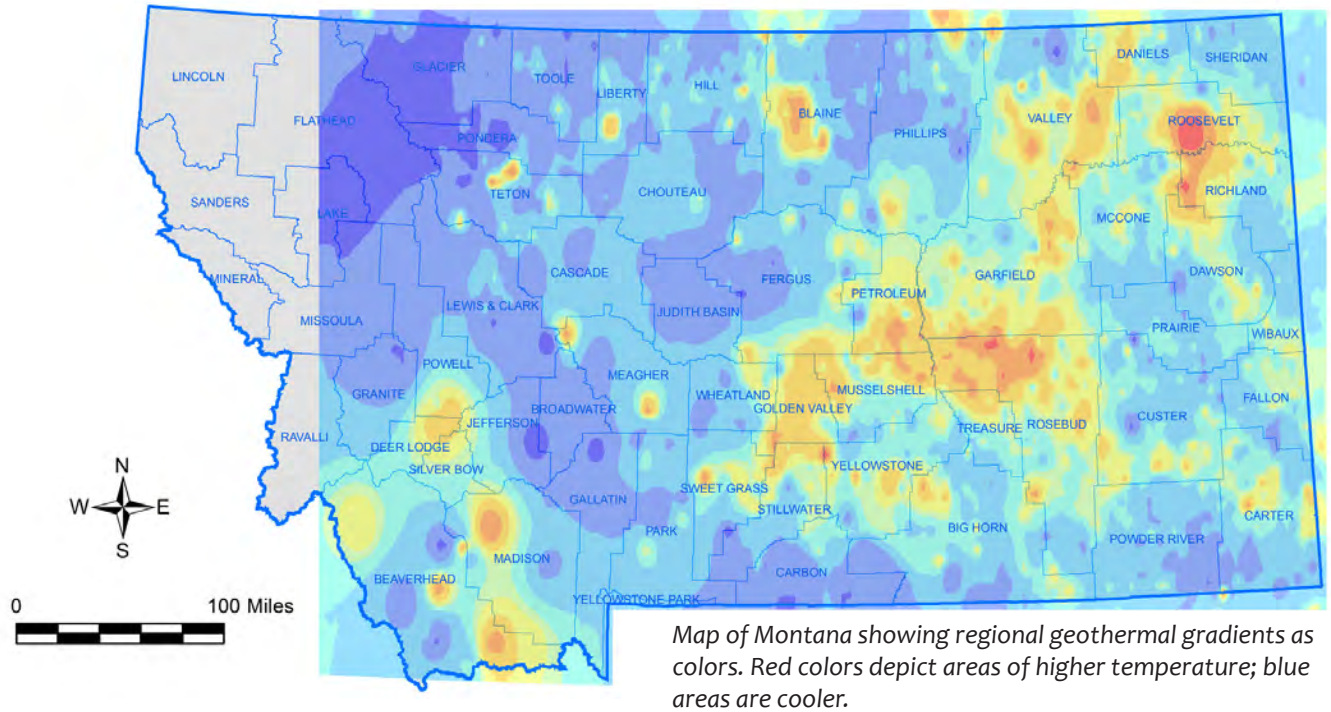
Montana's largest coal fields, such as the Otter Creek coal deposit, are found in the Powder River Basin (PRB) in southeastern Montana. The MBMG has conducted several coal availability studies that more accurately determine the quantity and distribution of mineable reserves. These studies were combined into a regional Coal Resource Assessment of the entire Montana PRB in cooperation with the USGS. Current and accurate coal resource estimates are essential for use in making local, State, and Federal energy and land-use policy decisions.

Geothermal Energy

Geothermal energy is heat that radiates from the Earth's interior. Because temperature generally increases with depth, groundwater deep in the subsurface is heated as it migrates through rock layers. Hot water and steam can be produced to the surface and utilized in heat exchangers or steam turbines to generate electrical power. Geothermal energy is an enormous resource that is both clean and sustainable.

Analysis of temperature data recorded in petroleum wells provides information on regional geothermal "hot spots," and identifies areas of higher temperature that could be utilized as geothermal energy sources for driving electric generators.

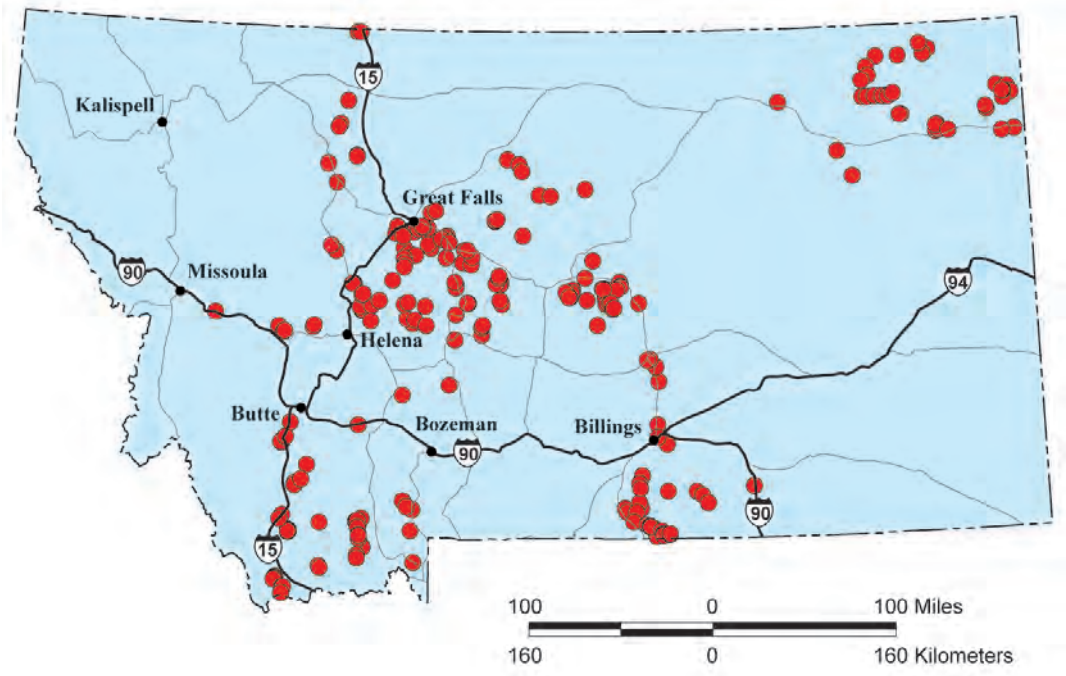
One cost-effective way to produce geothermal energy is to extract heat from the water that is co-produced from existing oil wells. Over time, many oil fields become depleted and the ratio of produced oil to water gradually decreases until the field is no longer economically viable. These depleted oil fields could be converted to water production and used as geothermal energy sources without additional drilling costs.



Map of Montana showing regional geothermal gradients as colors. Red colors depict areas of higher temperature; blue areas are cooler.

Hydraulic Fracturing Resources

Hydraulic fracturing ("fracking") is a critical component of drilling and completing productive wells in shale oil reservoirs such as the Bakken Formation in eastern Montana. The process cracks the deep shale to release oil or gas, and the cracks are held open with large quantities of sand or other "proppants." During the biennium, the MBMG was involved in a Montana Tech Petroleum Engineering Department project funded by the Montana Board of Oil and Gas Conservation to locate sources of naturally occurring proppant in Montana. MBMG geologists identified sandstone and sand deposits with the best proppant potential in Montana and collected over 300 samples for analysis.



Locations of quartz sandstone and sand samples for proppant analysis.

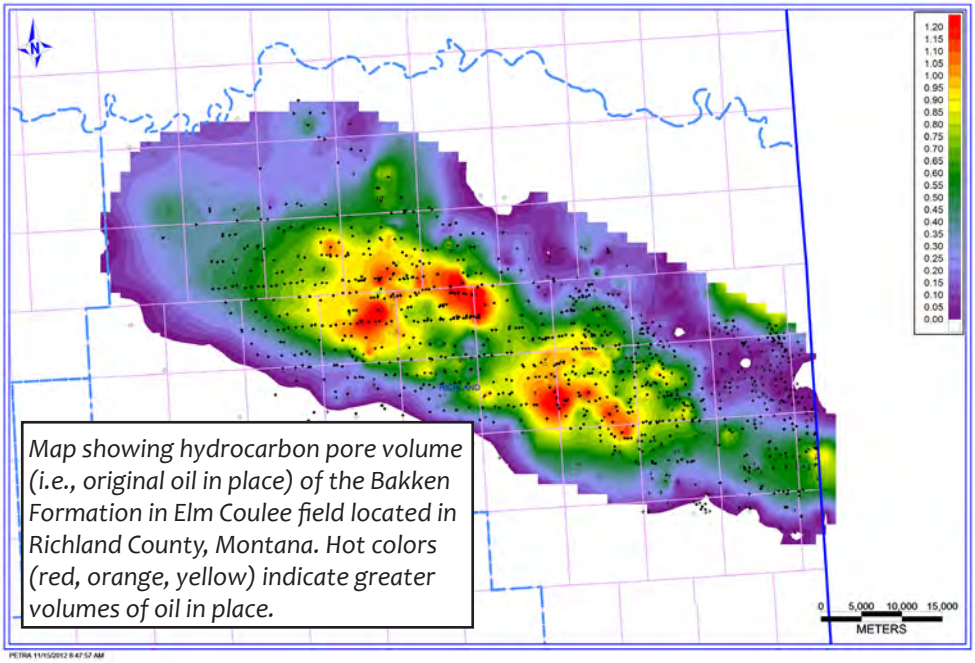
Montana Tech operates a sophisticated proppant testing laboratory that is being used to determine the suitability of the field samples for use as a proppant for hydraulic fracturing operations. The project will conclude in 2015, and will result in an MBMG-constructed web-server database of the results, accessible to the public.

Elm Coulee Field (Bakken) Reservoir Model

The Bakken Formation in eastern Montana and western North Dakota hosts one of the most important, rapidly developing oil resources in the United States. Montana's largest "Bakken" field—the Elm Coulee field in Richland County—contains over one billion barrels of oil and has been producing since the early 2000s.

It is expected that only about 5–10% of the original oil in place will be recovered during initial pumping or the primary recovery phase of Elm Coulee. To recover additional oil, enhanced oil recovery (EOR) processes must follow. These usually include injecting fluids such as carbon dioxide (CO_2) or water to mobilize additional oil so it can be captured by producing wells.

The MBMG and the Montana Tech Petroleum Engineering department have jointly developed a computer-based Elm Coulee reservoir model that will be used to test and simulate EOR methods, operations, and results. Simulating reservoir behavior prior to EOR will improve reservoir performance, increase oil recovery, and extend the life of the Elm Coulee field.



Map showing hydrocarbon pore volume (i.e., original oil in place) of the Bakken Formation in Elm Coulee field located in Richland County, Montana. Hot colors (red, orange, yellow) indicate greater volumes of oil in place.

EASTERN MONTANA PROJECTS

from our Billings field office

Groundwater Monitoring around Energy Development

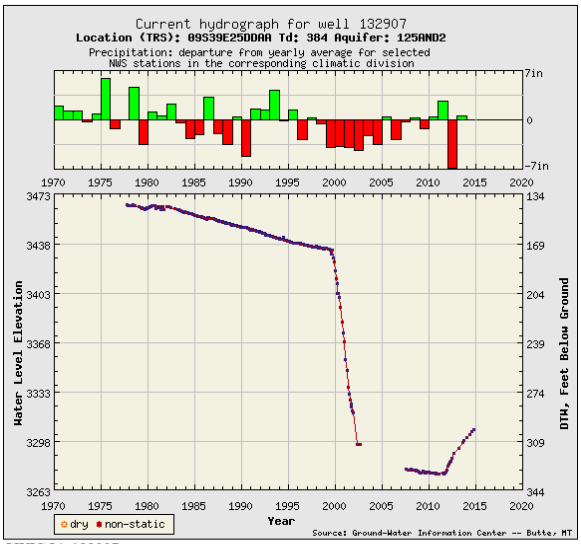
Oil and Gas

In cooperation with the Montana Department of Environmental Quality and the Department of Natural Resources and Conservation, an extensive Eastern Montana domestic well sampling program will be initiated in 2015. Focusing on characterizing aquifer properties rather than impact-related sampling will create a powerful tool for protecting landowners and industry by distinguishing between development-related changes to the water resource and naturally occurring changes.

Over 100 wells are targeted for sampling. Samples will be analyzed for a suite of inorganic and organic constituents, and overall aquifer characteristics will be summarized in a joint report between the MBMG and the DEQ.

This sampling program will complement previous and ongoing water-quality and -quantity monitoring in response to energy development in Eastern Montana, including:

- ongoing water-level monitoring of the Fox Hills aquifer,
- organic and inorganic groundwater and surface-water analysis in Sheridan, Roosevelt, Carbon, and Stillwater Counties (supported by DNRC and CBMPP), and
- pre-uranium production baseline water-quality sampling in Carter County.



GWIC Id: 132907
Site Name: MBMG MONITORING WELL WR-53
Location: 09S39E25DDAA
Total Depth: 384 feet
Number of Measurements: 310
Period of Record: 9/28/1977 - 10/1/2014 10:27:00 AM

Coal

Forty years of groundwater monitoring by the MBMG in and around coal mining in Rosebud and Big Horn Counties continues to illustrate the importance of long-term monitoring. Water levels in coal aquifers have begun to recover since the slow-down in coalbed methane production in 2013, but have not yet arrived at levels that would be associated with strictly coal-mine-related drawdown. Canadian and Australian groups have looked to the coal monitoring network established by the MBMG as a model for their own groundwater monitoring efforts.

Coalbed Methane

An annual report on quantity and quality of groundwater in areas being developed, or recently developed, for coalbed methane is made publicly available every year on the MBMG publications website. This report interprets water level and water chemistry data in terms of current and future development in the Powder River Basin. Long-term monitoring, funded by the Department of the Interior Bureau of Land Management, provides the platform for specific, issue-based studies such as a recently completed coal aquifer baseflow quantification effort. Using a combination of physical and chemical parameters, the contribution of coal aquifer groundwater to Powder River Basin streams was measured. The results from this work will be available through a Groundwater Investigation Program report in 2015.

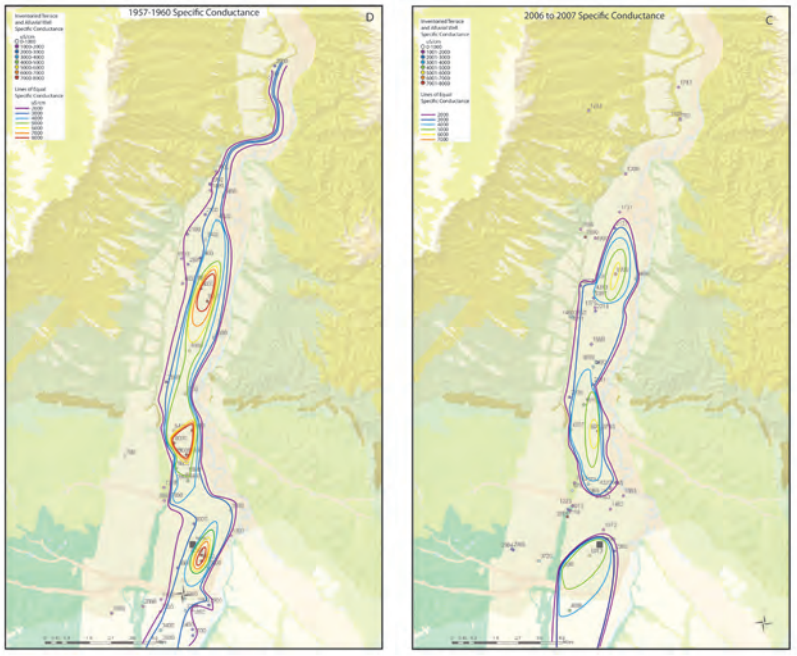
Regional Water Resource Investigations

Funded through Montana DNRC Renewable Resources Grants

Big Horn County

Evaluating the Influence of Irrigation on Groundwater Quality and Quantity in Northern Big Horn County

Previous work in the northern Bighorn Valley by the BHCD and the MBMG elucidated the important role irrigation ditches play in the groundwater supply to the alluvial aquifer used as the sole source of drinking water in rural Big Horn County. However, several observations made during that study call into question many long-held assumptions about irrigation and the role it plays in groundwater recharge and salinity. The groundwater model constructed under this project has the potential to examine the relative importance of several interrelated influences on groundwater quantity and quality and to quantify recharge sources to determine if prior evidence overstated the importance of ditches.



Groundwater salinity in the Bighorn Valley has improved since a 1959 assessment. The mechanism by which this improvement occurred is the focus of this study.

Stillwater County

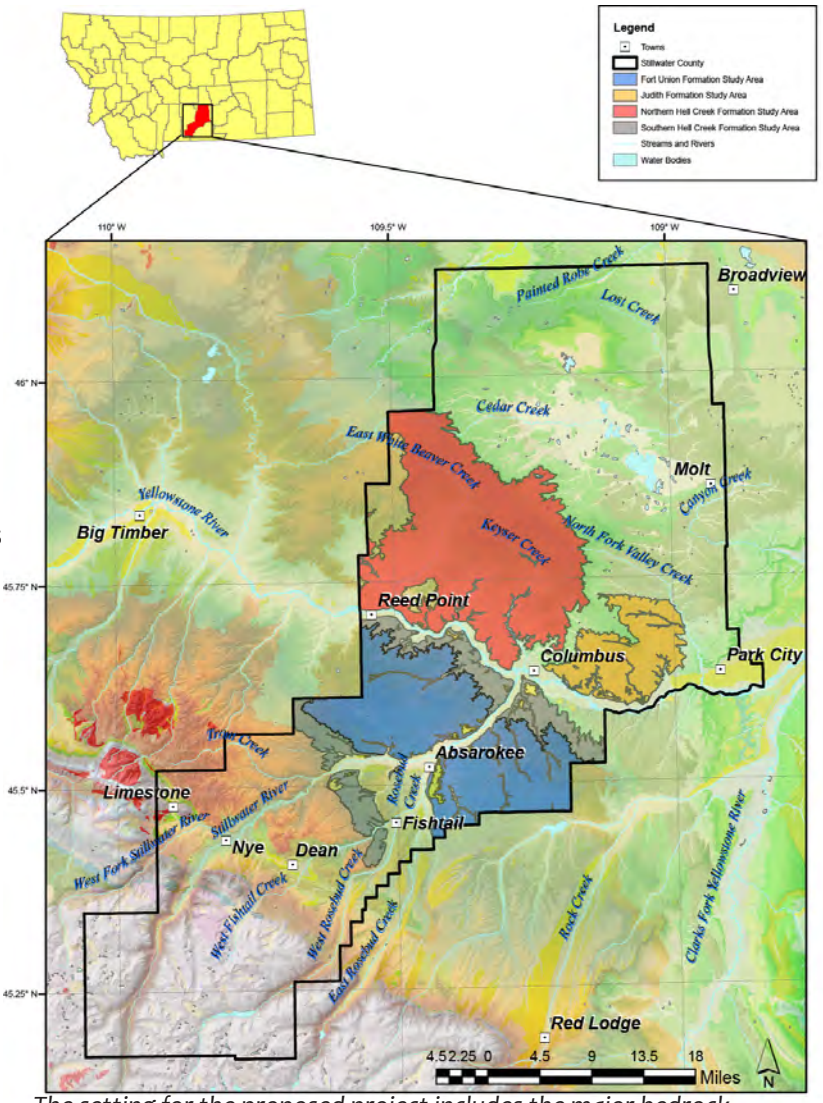
Assessing the Groundwater Resources of the Bedrock Aquifers in Stillwater County

The bedrock aquifers of Stillwater County supply water to over 3,000 sites for both agricultural and domestic use. Residential development is rapidly spreading into the foothills of the Yellowstone, Stillwater, and Rosebud Valleys, placing new demands on bedrock aquifers. Many of the shallower aquifers are geologically truncated from regional flow systems and have small local recharge areas; water availability seems to be dependent on significant low-elevation precipitation events and geological structures such as fault zones. More information on recharge areas and recharge rates is needed to make sound decisions regarding additional groundwater use.

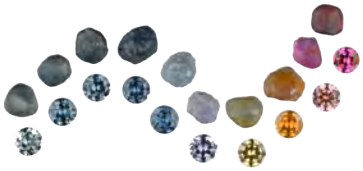
Carbon County

Groundwater and Surface Water Interaction in the Rock Creek Watershed

A recent study completed near Red Lodge on the east and west bench system determined that recharge is primarily from flood irrigation and irrigation-ditch leakage. Drought, land-use changes, or canal lining could reduce groundwater availability. Integrated groundwater and surface-water data are necessary to better manage and plan future development. Baseline data are being collected to provide the information necessary to evaluate effects of future development or land-use changes in the area and help understand how to preserve the current aquifer conditions.



The setting for the proposed project includes the major bedrock aquifers in central Stillwater County.



MINERAL MUSEUM

The Mineral Museum on the Montana Tech campus began with the purchase of 177 specimens within 6 months of the founding of the Montana School of Mines, in 1901. Today, the MBMG curates over 12,000 specimens from all over the world, with new acquisitions every year.

This biennium the Museum had approximately 14,000 visitors, including 2,813 visitors in groups, both students and adults.

A total of 130 new specimens were added this biennium, including:

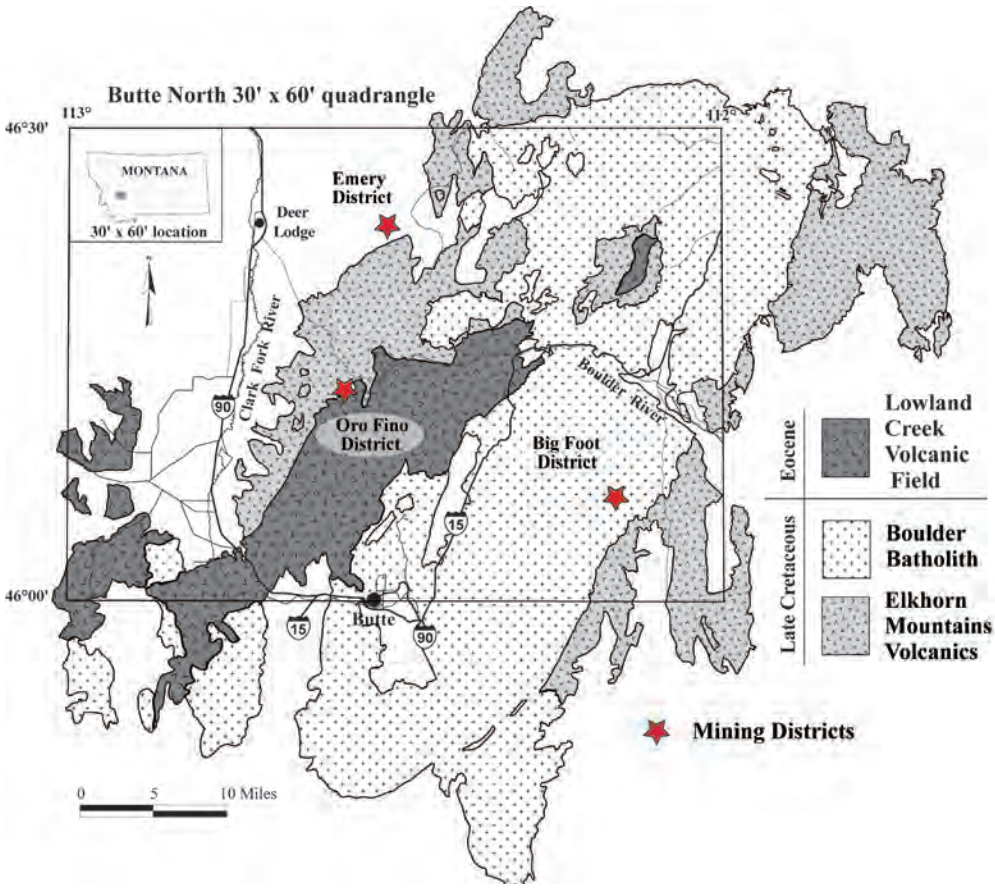
- A collection of native copper specimens from local collector Mr. Joe Slouber.
- Montana mineral specimens from Mary Merk Clark, who donated her collection to the Beaverhead County Museum, who gave the Mineral Museum a portion of her collection.
- Meteorites from Mr. Marlin Cilz, including a rare pallasite (meteorite) believed to be from Montana.
- In February 2014, the Mineral Museum purchased a sculpture of Butte covellite ore from a well-known mineral collector and dealer, Mr. Buzz Gray of Missoula. Mr. Gray acquired a number of covellite pieces from Mr. Perry B. Davis, the sculptor, and offered to sell the Museum one of the pieces, named “Midnight Blue.” Additional information about Mr. Davis can be found on his website (http://perrybdavis.com). The covellite ore is unique for its size and richness.

- A new display on sapphire mining in Montana by Dr. Berg.
- Stillwater Mining has donated rock samples to a future display of Montana’s Stillwater Complex.

The Museum continues to improve lighting, with the addition of LED lights in individual cases.

The Museum also hosted the Montana Mineral Collectors again in 2013.

ECONOMIC GEOLOGY



Regional igneous geology and the location of mining districts that are currently being investigated by MBMG scientists in the Butte North 30' X 60' quadrangle.

Future exploration for mineral resources is expected to focus on past-producing historic mining districts throughout the State. This exploration will be driven by past exploration successes of economically recoverable resources. Two successful mines, Montana Tunnels and Golden Sunlight, were both discovered in historic mining districts. Since it is believed most shallow mineral resources have been discovered, there is a trend in the industry to search for deeper ore bodies with a focus on deep-seated copper and gold porphyries. High metal prices have driven past exploration efforts. Today metal prices are depressed and mining companies are having difficulty raising funds for exploration efforts.

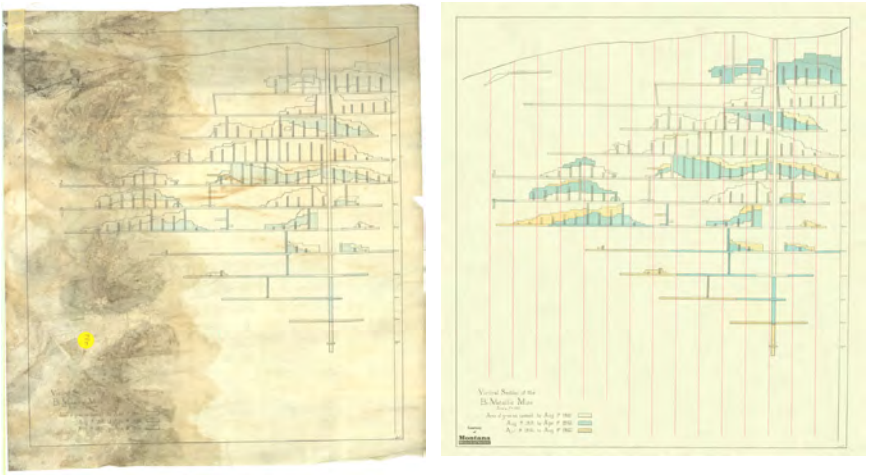
In spite of these financial difficulties, Kennecott Exploration Co., Tintina Resources, Inc., and U.S. Rare Elements Inc. are conducting exploration programs in historic mining districts in Montana. Kennecott Exploration Co. is exploring the historic Copper Cliff mining district, located near the ghost town of Garnet, for a copper porphyry deposit. Exploration efforts began with geophysical work and expanded to a drilling program that was permitted and started this year. Past exploration efforts conducted by Tintina Resources, Inc. led to a successful discovery of a massive sulfide copper–cobalt–silver deposit in the Black Butte area near White Sulphur Springs. The company is currently completing their permitting to drive an exploration decline to further delineate the deposit. U.S. Rare Earths Inc. received funding to conduct a drilling program in the Lemhi Pass Thorium district to search for rare earth element deposits. Permitting for the exploration program was completed this year, and the company received a permit from the U.S. Forest Service to remove material from one of the historic mine dumps for metallurgical testing.

The MBMG started an economic geology program in 2014 in response to renewed interest in exploration for deep-seated mineral resources in past-producing historic mining districts. Geologic studies have not been conducted in most historic mining districts for over 40 years, over which time there have been many changes in the economics of the mining industry, exploration methods, analytical techniques, data interpretation, and ore deposit modeling. The MBMG's economic geology program will conduct detailed studies on mining districts and update our understanding of the genesis of mineral resources throughout the State. Such studies will help identify areas that may have potential for future minerals exploration. Past investigations of geophysical, geochemical, and geologic data will be incorporated and updated with new isotope geochemistry, fluid inclusion, and mineralogical data.

The MBMG's geologic mapping program has contributed detailed mapping of the mineral resource geology in these historic mining districts. Investigations on the mining districts related to the Boulder Batholith within the Butte North 30' X 60' quadrangle began this year (see figure, above). Samples were collected and processed from the Emery, Oro Fino, and Big Foot mining districts. The Emery district is located east of Deer Lodge and represents an area on the northwest edge of the Boulder Batholith. The Oro Fino district is south of Emery and east of Warm Springs and covers an area along the west contact of the batholith. The Big Foot district is located north of Whitehall along the State Creek drainage system and covers an area on the east side of the Boulder Batholith. Analysis is still pending for the samples collected during this year's field season. As the program is developed, more mining districts will be included from other regions.

DATA PRESERVATION

The MBMG has long committed resources to the preservation of geologic, geophysical, engineering, and water data created during Montana's historic development of its natural resources. The data represent an enormous, and often irreplaceable, information source for geologists, engineers, students, educators, lawyers, legislators, consultants and the general public. MBMG's Data Preservation Program currently maintains 4,668 historical mine property files, 7,939 mining-related maps, 4,900 geophysical logs, more than 15,000 thin sections, samples and polished rock sections from the Butte underground mines, and over 407,000 aerial photos.



Before and after images of a vertical section map of the Granite Bi-Metallic mine, digitally restored by the MBMG.

While the MBMG has accepted donated information for many years, federal funds made available in 2005 through the USGS National Geological and Geophysical Data Preservation Program (NGGPP) provided small grants to identify, rescue, and preserve archival material in danger of being destroyed or lost.

The 64th Montana Legislature appropriated funds to help preserve mining and geologic data and stressed the importance of eastern Montana non-proprietary oil, gas, and coal data to ensure that data about energy resources are preserved along with data from hard rock mining. Because interest in eastern Montana energy development is currently high, finding non-proprietary data is difficult. Thus far, the MBMG received and is cataloging geophysical logs, formation top cards, and manuscripts donated by the family of a retired geologist whose primary area work was in eastern Montana oil and gas.

The Legislative appropriation also provided funds to hire additional staff (including students) to scan and restore the backlog of documents in its repositories, equip staff with work stations and computers, purchase computer servers to meet data storage requirements, ensure data system backup and redundancy, and make digitized archival information publicly available.

In the past year, the Data Preservation Program received an aerial photo collection from the Forest Service and a collection of information regarding the proposed New World mine. The mine was never developed, and the property was ultimately transferred to public ownership and withdrawn as a potential mining location. The New World collection contains unique mineralogical and geologic data useful in the evaluation of other epithermal gold deposits.

The Mining Archives program also collaborated with the Montana Historical Society to digitize and electronically restore several hundred technical maps of the historic Granite Bi-Metallic and Hope mines. The Society retains ownership of the documents, and the MBMG will provide electronic versions through its Data Preservation web portal.

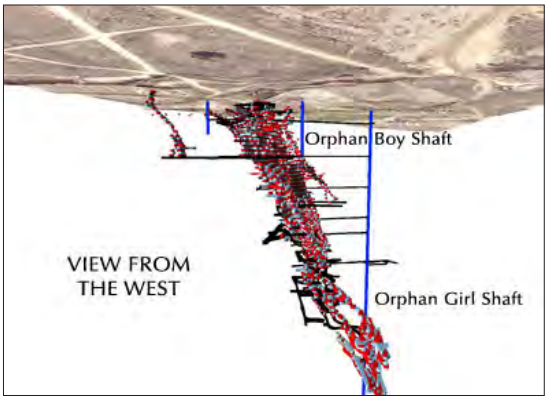
MBMG Data Preservation staff and students cataloging and storing mine core.

In June 2014, the Mining Archives Program accepted a donation from Butte–Silver Bow of 488 trays (approximately 4 miles) of drill core obtained from subsurface exploration of 14 Butte Hill mines. The core had been stored in the Original mine hoist house building. Some of the samples had already disintegrated, and the remainder were in danger of being lost. With the rescue by the MBMG, the core samples represent an irreplaceable snapshot of the mineralogy and geochemistry of the world-class Butte copper deposit from mines that are now completely inaccessible due to underground flooding.

ANALYTICAL LAB

The Analytical Laboratory provides inorganic and organic analyses in support of the MBMG's research projects. The laboratory has expanded their capabilities with the recent addition of a Picarro $\delta^{13}C$ High-Precision Isotopic carbon dioxide (CO_2) analyzer, G2131-*i,* which will allow for ^{13}C isotopic analysis of CO_2 in water. A Costech Combustion Module was added to the Picarro G2131-I to allow ^{13}C isotopic analyses of solid samples. In addition, an Aurora 1030 Wet Oxidation TOC Analyzer was added to provide the capability of analyzing organic and inorganic carbon in water samples.

The laboratory also purchased a new ICP-MS, the ICAP-Q from Thermo Scientific. This instrument replaced the aging X-series ICP-MS and will be used for trace-metal analyses. The ICP-Q allows for low detection of elements and has a linear detection range of over 8 orders of magnitude.



GIS LAB

The past few years have been a busy time for the GIS staff at the MBMG; many changes in how our maps and data are delivered have occurred. GIS technology is continually evolving to provide better data, analysis, and maps. The MBMG is leveraging these advancements to provide access to better public information.

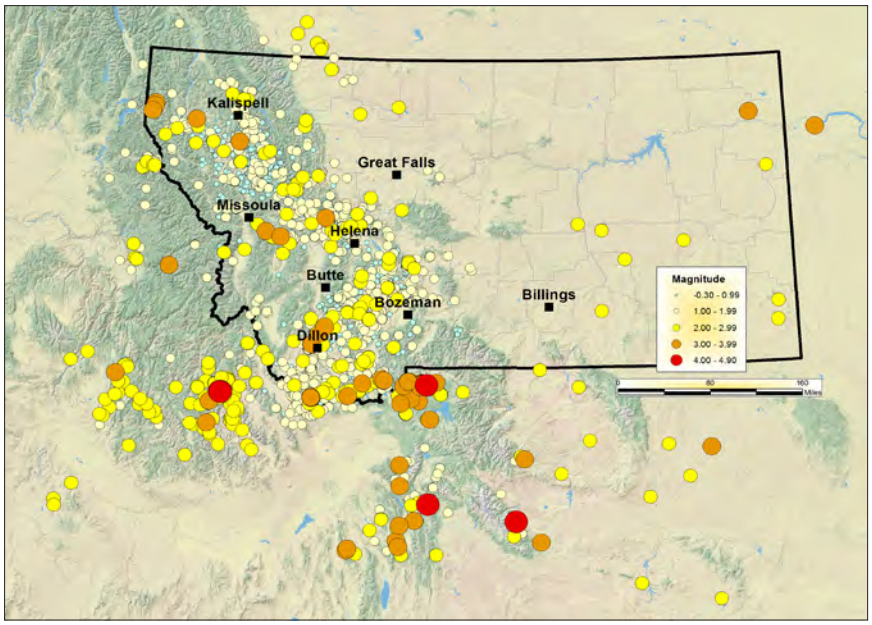
Many of our data layers are now available as online map services, intended primarily for users of ESRI (GIS mapping) software. ArcGIS Server allows access to our 1:500,000 scale geologic maps data, GWIC wells database, earthquakes, and a few other data layers as well. Data from these various layers can also be downloaded for offline use. The software development team is further leveraging these online map services to build online mapping applications for MBMG and public use.

The GIS shop has moved forward with developing and converting data into file geodatabases. Our previous Arc/Info data type worked well for many years, but has been replaced with a much more robust data model. The geodatabase model has enabled us to construct our 1:500,000 State Geologic Map, and a few iterations of our 1:100,000 scale geologic maps.

Much of our geologic mapping efforts have focused on the 1:100,000 geologic map series. This continues to be a large part of the work of both our field geologists and the GIS staff. In late 2014 or early 2015, we will be releasing an online mapping service with all of the MBMG 30' x 60' geologic maps as an online mapping service with download available. The data included in this layer is our 'legacy' data. The term legacy is used to denote the fact it has not been refined to integrate with other/adjacent data. It's a first effort toward integrating our geologic data.

A more current project is to integrate our 30' x 60' maps into a single unified geologic map data set. Our legacy data sets (identified above) are the starting point, with geologists actively engaged in the development and production of this layer. It's an ongoing effort, and the MBMG is committed to developing future geologic maps into this database model, essentially becoming our new way of doing business. The task requires significant coordination & communication among staff involved in the project.

EARTHQUAKE STUDIES



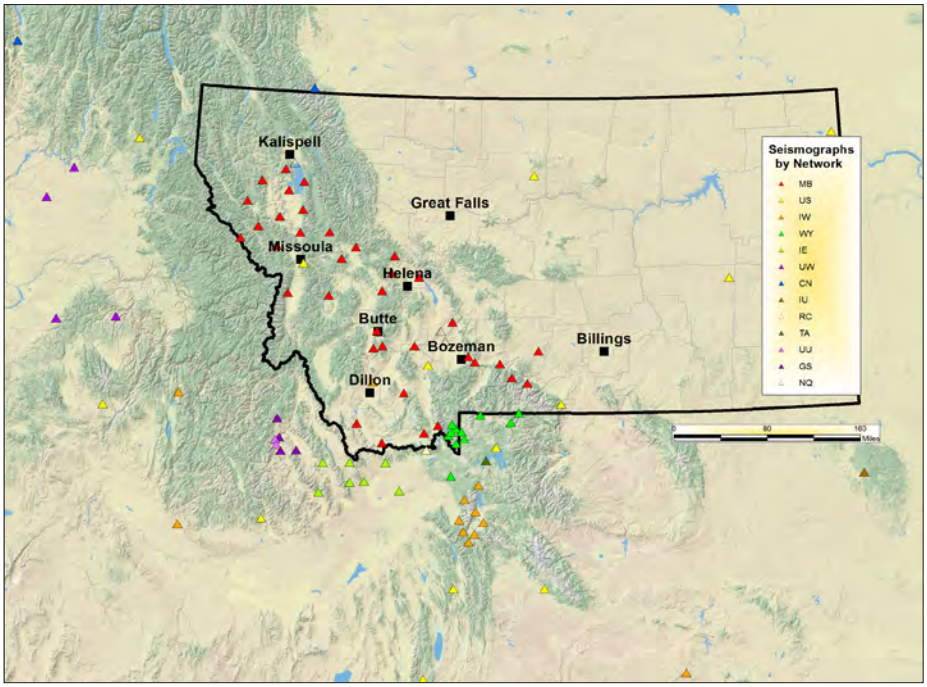
Epicenter locations for 4,135 earthquakes located by the MBMG from July 1, 2012 to June 30, 2014.

Western Montana has a history of large, damaging earthquakes and remains seismically active. Most of these earthquakes (including the 1925 magnitude 6.6 Clarkston earthquake centered north of Three Forks, and the magnitude 6.3 and 6.0 Helena earthquakes in 1935) occur 3 to 10 miles deep along faults that do not extend to the Earth's surface. The seismic hazards associated with these "blind" faults cannot be evaluated with traditional surficial mapping of faults and are best studied with data from a permanent network of seismograph stations. As the population and infrastructure of earthquake-prone western Montana continues to grow, the exposure to seismic hazards—the risk—increases.

The MBMG operates a network of 38 seismic monitoring stations throughout western Montana, the most seismically active region of the State. Four additional stations operate in less active eastern Montana. Other regional seismic monitoring centers in Yellowstone National Park, central Idaho, and southern Canada exchange seismic data with the MBMG and provide additional monitoring coverage near Montana's borders. The MBMG has installed NetQuakes seismographs at four homes or fire stations in western Montana. These small instruments detect significant ground motions at urban locations and send the data to a central server via the internet.

The MBMG records a total of 196 channels of seismic data from 103 local and regional stations in 13 different networks. These seismic data are used to detect and report earthquake locations and magnitudes for significant earthquakes within 2½ to 3 minutes of their occurrence to the National Earthquake Information Center. State and Federal agencies (Montana Disaster and Emergency Services, Montana Dam Safety Program, Confederated Salish and Kootenai Tribes Safety of Dams Program, and the U.S. Geological Survey), the media, and the public use this information. As part of its routine earthquake cataloging procedure, the MBMG determined times, locations, and magnitudes for 4,135 earthquakes with magnitudes ranging from -0.4 to 4.9 from July 1, 2012 to June 30, 2014.

Real-time views of seismograms from the MBMG network are available on the MBMG Earthquake Studies Office website (http://mbmgquake.mtech.edu/), along with a listing of recent earthquakes and other information about seismic hazards in Montana. Information about Montana seismicity, faults, and earthquake hazards is available at: http://data.mbmg.mtech.edu/mapper/.



Seismograph stations connected in real time to the Earthquake Studies Office and used to locate earthquakes during 2014. Network codes are: MB, MBMG; US,USGS National; IW, USGS Intermountain West; WY, University of Utah Yellowstone; IE, Idaho National Labs; UW, University of Washington; CN, Canadian national; IU, Global Seismograph Network; RC, BYU Idaho; TA, Transportable Array, UU, University of Utah temporary stations; GS, USGS temporary stations; and NQ, NetQuakes strong motion stations.

INFORMATION SERVICES

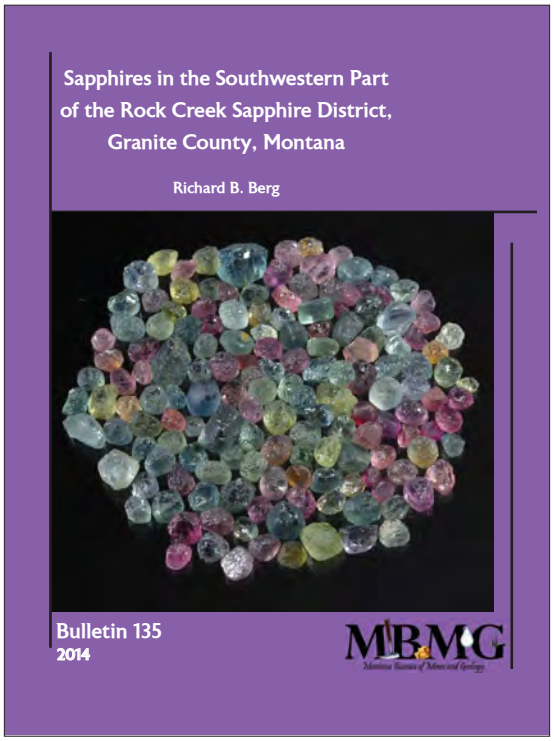
The Information Services Division is responsible for creating, editing, and distributing MBMG publications and reports to the public, both through our Publication Sales office and the MBMG's website.

Visit the MBMG site, http://www.mbmg.mtech.edu, or come see us in the Natural Resources Building.

New publications in this biennium:

Bulletins

Bulletin 135, Sapphires in the southwestern part of the Rock Creek sapphire district, Granite County, Montana, 86 p., Berg, R.B., 2014.



Geologic Maps

GM 63, Geologic map of the Avon 7.5' quadrangle, Powell County, Montana, Trombetta, M.J., and Berg, R.B., 2012.

GM 64, Clinker distribution and age in the Powder River structural basin, 7 p., Heffern, E.L., Reiners, P.W., and Riihimaki, C.A., 2013.

Ground-Water Atlas Series

GWAA 3A, Groundwater resources of the Middle Yellowstone River area: Treasure and Yellowstone counties, Montana Part A—Descriptive Overview and Water-Quality Data, 82 p., Madison, J.P., LaFave, J.I., Patton, T.W., Smith, L.N., and Olson, J.N., 2014.

GWAA 4A, Groundwater resources of the Lolo-Bitterroot area: Mineral, Missoula, and Ravalli Counties, Montana Part A—Descriptive Overview and Water-Quality Data, Smith, L.N., LaFave, J.I., and Patton, T.W., 2013.

GWAA 5B-04, Groundwater quality in basin-fill and bedrock aquifers, Deer Lodge, Granite, Powell, and Silver Bow Counties, LaFave, J.I., 2013.

Informational Pamphlets

IP 8, Water levels in the Upper West Bench alluvial aquifer, Red Lodge, Montana, 8 p., Carstarphen, C., Patton, T.W., and LaFave, J.I., 2014.

IP 9, Tracking Montana's groundwater, 10 p., LaFave, J.I., 2014.

Open-File Reports

MBMG 616 a, Glendive—Top of the Bearpaw Shale/Pierre Shale, Bergantino, R.N.

MBMG 616 b, Glendive—Top of the Judith River Formation, Bergantino, R.N.

MBMG 616 c, Glendive—Thickness of the Judith River Formation, Bergantino, R.N.

MBMG 616 d, Glendive—Top of the Claggett Shale, Bergantino, R.N.

MBMG 616 e, Glendive—Top of Eagle Formation/Gammon Shale, Bergantino, R.N.

MBMG 616 f, Glendive—Top of Kootenai Formation, Bergantino, R.N.

MBMG 616 g, Glendive—Thickness of the Kootenai Formation, Bergantino, R.N.

MBMG 617 a, Forsyth—Top of the Bearpaw Shale, Bergantino, R.N.

MBMG 617 b, Forsyth—Top of the Judith River Formation, Bergantino, R.N.

MBMG 617 c, Forsyth—Thickness of the Judith River Formation, Bergantino, R.N.

MBMG 617 d, Forsyth—Top of the Claggett Shale, Bergantino, R.N.

MBMG 617 e, Forsyth—Top of the Eagle Formation/Gammon Shale, Bergantino, R.N.

MBMG 617 f, Forsyth—Thickness of the Eagle Formation/Gammon Shale, Bergantino, R.N.

MBMG 617 h, Forsyth—Thickness of the Kootenai Formation, Bergantino, R.N.

MBMG 618 a, Glasgow—Top of the Bearpaw Shale, Bergantino, R.N.

MBMG 618 b, Glasgow—Top of the Judith River Formation, Bergantino, R.N.

MBMG 618 c, Glasgow—Thickness of the Judith River Formation, Bergantino, R.N.

MBMG 618 d, Glasgow—Top of the Claggett Shale, Bergantino, R.N.

MBMG 618 e, Glasgow—Top of Eagle Sandstone/Gammon Shale, Bergantino, R.N.

MBMG 618 f, Glasgow—Top of the basal Colorado "Dakota" sandstone, Bergantino, R.N.

MBMG 618 g, Glasgow—Top of the Kootenai Formation, Bergantino, R.N.

MBMG 618 h, Glasgow—Top of the basal Kootenai "Lakota" Formation, Bergantino, R.N.

MBMG 618 i, Glasgow—Thickness of the Kootenai Formation, Bergantino, R.N.

MBMG 620, U.S. Fish & Wildlife Service Region 6 Environmental Contaminants Program, Montana—Impacts of oil exploration and production to the Northeast Montana Wetland Management district, 264 p., Rouse, D.R., Nelson, K.J., and Reiten, J.C.

MBMG 621, Geologic map of the Polaris 7.5' quadrangle, southwestern Montana, Lonn, J.D., and Lewis, R.S.

MBMG 622, Geologic map of the Butte South 30' x 60' quadrangle, southwestern Montana, McDonald, C., Elliott, C.G., Vuke, S.M., Lonn, J.D., and Berg, R.B.

MBMG 623, Geologic map of the Line Point quadrangle, Boundary County, Idaho and Lincoln County, Montana, Burmester, R.F., Breckenridge, R.M., McFaddan, M.D., Lewis, R.S., and Lonn, J.D.

MBMG 624, Geologic map of the Canuck Peak quadrangle, Boundary County, Idaho and Lincoln County, Montana, Burmester, R.F., Breckenridge, R.M., McFaddan, M.D., Lewis, R.S., and Lonn, J.D.

MBMG 625, Geologic map of the Curley Creek quadrangle, Boundary County, Idaho and Lincoln County, Montana, Breckenridge, R.M., Burmester, R.F., Lewis, R.S., McFaddan, M.D., and Lonn, J.D.

MBMG 626, Geologic map of the Leonia quadrangle, Boundary County, Idaho and Lincoln County, Montana, Burmester, R.F., McFaddan, M.D., Breckenridge, R.M., Lewis, R.S., and Lonn, J.D.

MBMG 627, Geology of the Butte mining district, Montana, Houston, R.A., and Dilles, J.H.

MBMG 628, Hydrologic investigation of the North Hills Study area, Lewis and Clark County, Montana, Groundwater Modeling Report, 90 p., Waren, K.B., Bobst, A.L., Swierc, J.E., and Madison, J.D.

MBMG 629, Geologic map of the Lockhart Meadows 7.5' quadrangle, west central Montana, Hargrave, P.A., and Berg, R.B.

MBMG 630 a, Jordan—Top of the Bearpaw Shale, Bergantino, R.N.

MBMG 630 b, Jordan—Top of the Judith River Formation, Bergantino, R.N.

MBMG 630 c, Jordan—Thickness of the Judith River Formation, Bergantino, R.N.

MBMG 630 d, Jordan—Top of the Claggett Shale, Bergantino, R.N.

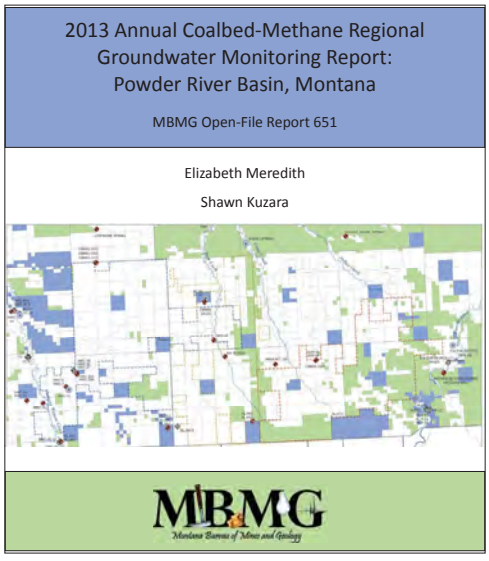
MBMG 630 e, Jordan—Top of the Eagle Formation/Gammon Shale, Bergantino, R.N.

MBMG 630 f, Jordan—Thickness of the Eagle Formation/Gammon Shale, Bergantino, R.N.

MBMG 630 g, Jordan—Top of the Kootenai Formation, Bergantino, R.N.

MBMG 630 h, Jordan—Thickness of the Kootenai Formation, Bergantino, R.N.

MBMG 631, 2012 Annual coalbed methane regional groundwater monitoring report: Powder River Basin, 90 p., Montana, Meredith, E., and Kuzara, S.



MBMG 632, Landslide map of the Big Sky area, Gallatin and Madison counties, Montana, Vuke, S.M.

MBMG 633, Geologic map of the Fan Mountain, Lone Mountain, and Gallatin Peak 7.5' quadrangles, Madison Range, Madison and Gallatin Counties, Montana, 27 p., Vuke, S.M.

MBMG 634, Geologic map of the Jumbo Mountain 7.5' quadrangle, Beaverhead County, Montana and Lemhi County, Idaho, Lonn, J.D., Stanford, L.R., McFaddan, M.D., Lewis, R.S., and Burmester, R.F.

MBMG 635, Geologic map of the Mount Powell 7.5' quadrangle, southwestern Montana, 22 p., Elliott, C.G., Smith, L.N., and Lonn, J.D.

MBMG 636, Hydrogeologic investigation of the Scratchgravel Hills study area, Lewis and Clark County, Montana, Interpretive Report, 63 p., Bobst, A.L., Waren, K.B., Butler, J.A., Swierc, J.A., and Madison, J.D.

MBMG 637, Hydrogeologic investigation of the Beaverhead River study area, Beaverhead County, Montana, 132 p., Abdo, G., Butler, J., Myse, T., Wheaton, J., Snyder, D., Metesh, J., and Shaw, G.

MBMG 638, Hydrogeologic investigation of the Beaverhead River study area, Beaverhead County, Montana, Groundwater Modeling Report, 78 p., Butler, J.A., and Abdo, G.

MBMG 640, Spring and stream water quality, Powder River Basin, Montana, 54 p., Wheaton, J., Meredith, E., and Rose, J.

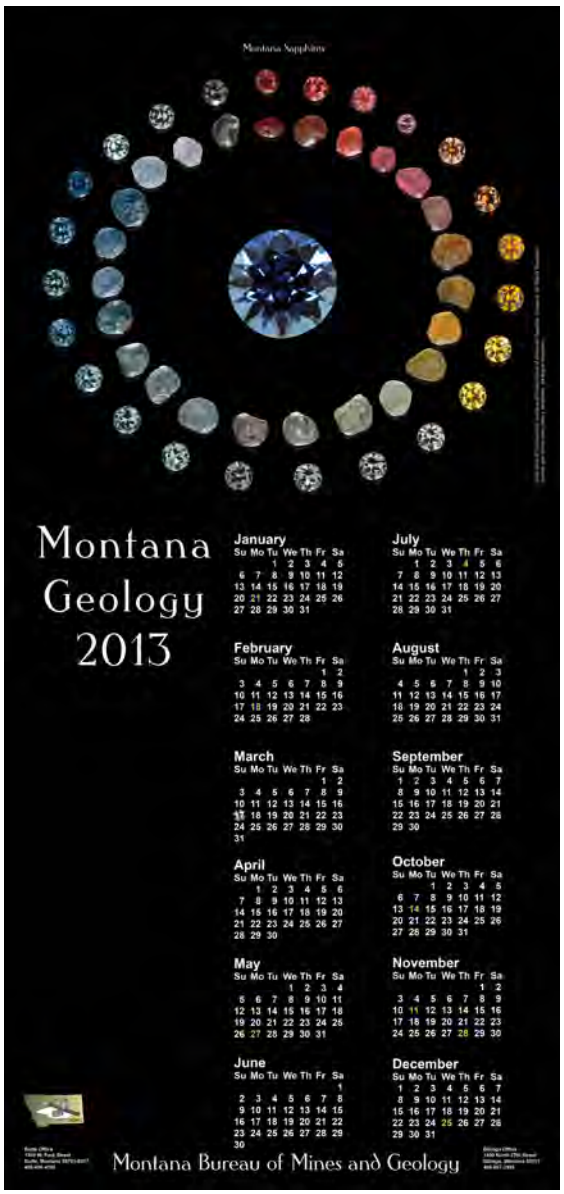
MBMG 642, Geologic map of the Clarkston Valley, Broadwater and Gallatin counties, west-central Montana, 16 p., Vuke, S.M., and Stickney, M.C.

MBMG 643, Hydrogeologic Investigations of the Scratchgravel Hills study area, Lewis and Clark County, Montana, Groundwater Modeling Report, 68 p., Butler, J.A., Bobst, A.L., and Waren, K.B.

MBMG 645, Geologic map of the Stillwater Complex within the Beartooth Mountains Front Laramide Triangle Zone, south-central Montana, 21 p., Geraghty, E.

MBMG 646, Hydrogeologic investigation of the Scratchgravel Hills study area, Lewis and Clark County, Montana—Technical Report, 234 p., Bobst, A.L., Waren, K.B., Butler, J.A., Swierc, J.A., and Madison, J.D.

MBMG 648, Geologic map of the Bozeman 30' x 60' quadrangle, southwestern Montana, 44 p., Vuke, S.M., Lonn, J.D., Berg, R.B., and Schmidt, C.J.



Miscellaneous Publications

MISC 55, Montana Bureau of Mines and Geology 2013 Calendar: Montana Sapphires, 2012.

MISC 57, Montana Bureau of Mines and Geology 2014 Calendar: Capitol Rock, 2013.

Reports of Investigation

Report of Investigation 22, Streamside characterization of Blacktail and Silver Bow Creeks: A continuous tracer injection investigation conducted during baseflow conditions in an urban area impacted by mining: Butte, Montana, 152 p., Tucci, N.J., 2014.

Information Services Statistics for this Biennium

Publication Sales:

- 1,299 titles
- 11,452 items sold
- 66 items published/released

Data downloaded:

- 879 titles
- **270,038 files**

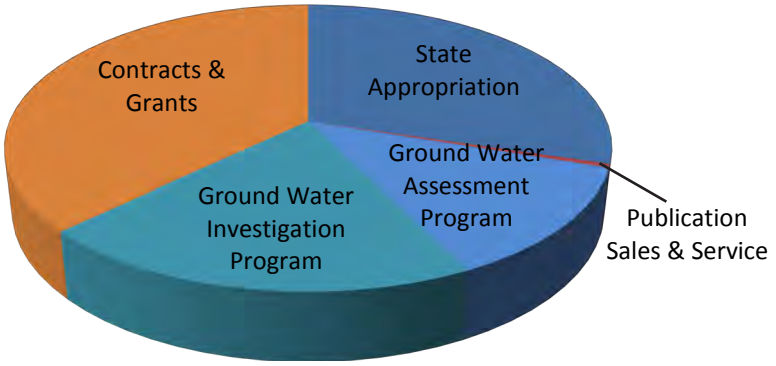
FINANCES

The Montana Bureau of Mines and Geology was established in 1919 to compile and publish information relative to the geology of Montana. The main office is on the campus of Montana Tech in Butte, and a second office is in Billings at 101 Grand Avenue. Our staff is composed of about 65 permanent employees in Butte and Billings, and about 30 students from Montana Tech, University of Montana, Montana State University, and MSU-Billings.

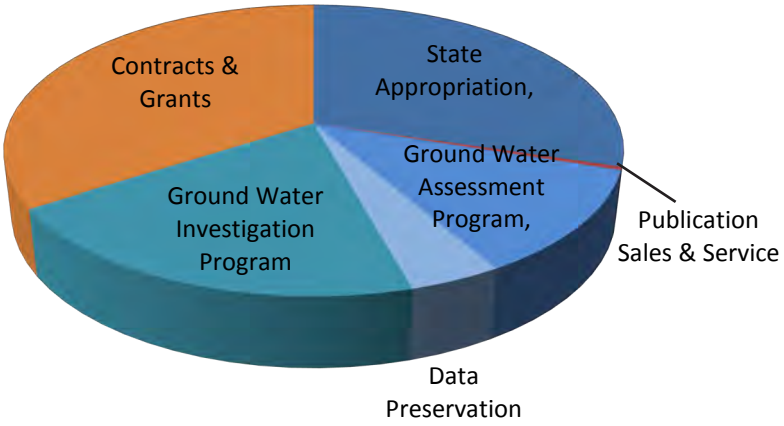
Funding for the past biennium came from six categories: (1) a biennial appropriation from the State's general fund to maintain core programs; (2) a biennial appropriation from the State's general fund for the Ground Water Investigation Program; (3) biennial appropriations from the State's special accounts for the Ground Water Assessment Program; (4) contracts and grants derived through agreements with variety of Federal, State, and local organizations to address specific issues of mutual interest to the sponsoring organization and the MBMG; (5) income from sales of MBMG publications; and (6) a special one-time-only appropriation for Data Preservation provided by the 2013 Legislature, reflected in the FY2014 chart.

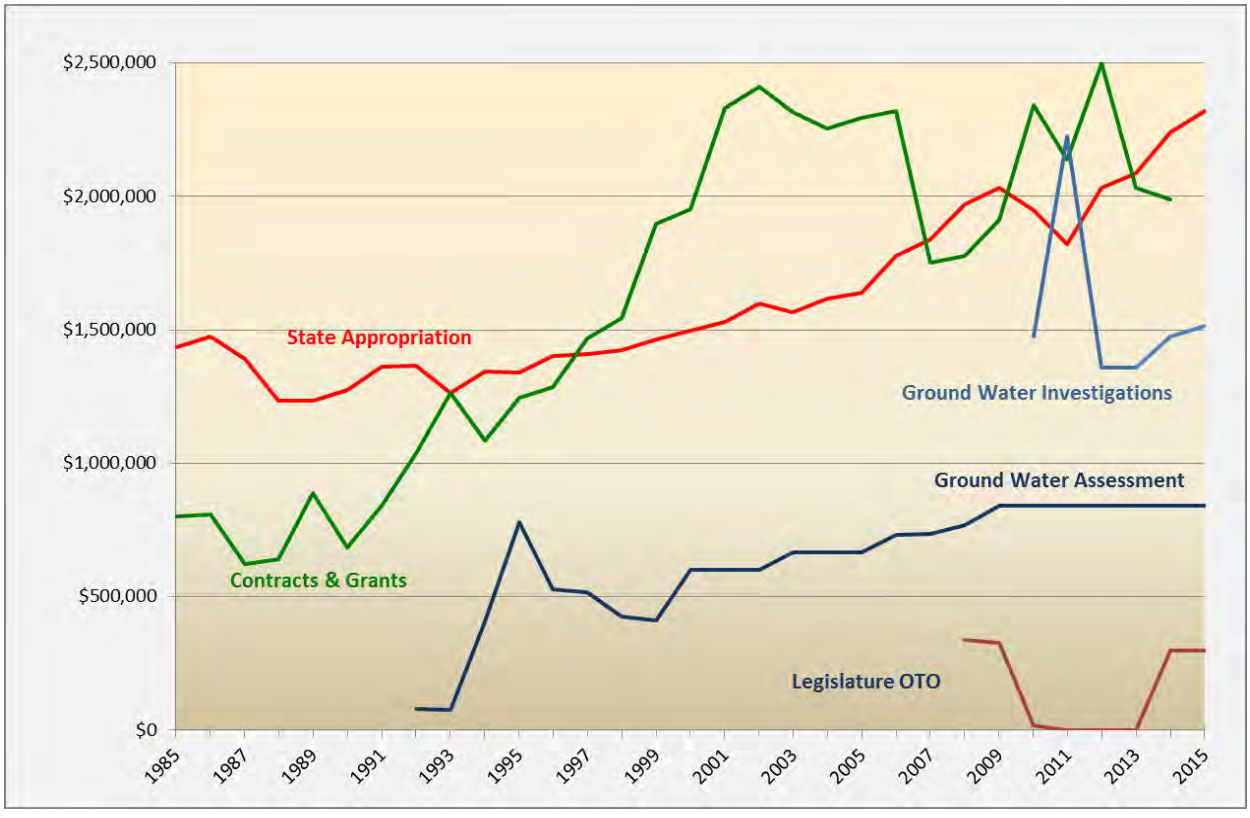
The long-term trend for the four major sources of funding continues upward at a modest rate; the generosity of the Montana Legislature and Governor is reflected in the steady growth of the core geologic programs as well as the recent addition of the new ground water program. Many of the projects under contracts and grants rely on partial state support (matching funds); growth of the MBMG in this area will continue to reflect that relationship.

FY 2013



FY 2014





MBMG STAFF

Director's Office

John J. Metesh, Director and State Geologist
Heather Holland, Administrative Assistant

Accounting

Sara Richards, Accounting Associate

Analytical

Jacqueline Timmer, Chief Analytical Lab, Chemist
Ashley Huft, Chemist
Steve McGrath, Analytical Chemist

Computer Services and Geographic Information Systems

Jeff Johnson, Computer Support Specialist
Ken Sandau, GIS Specialist
Paul Thale, GIS Specialist

Information Services

Susan Barth, Chief Information Services Division, Publications Editor, Assistant Research Professor
Nancy Favero, Information Systems Technician
Susan Smith, Geologic Cartographer
Bette Wasik, Administrative Assistant

Research Staff

Thomas W. Patton, Chief Research Division, Research Professor, Senior Research Hydrogeologist

Ginette Abdo, Senior Research Professor, Hydrogeologist, Program Manager–Ground Water Investigation Program (GWIP)
Matthew Berzel, Professional Scientist, Hydrogeologist
Dan Blythe, Professional Scientist, Hydrogeologist
Andrew Bobst, Associate Research Professor, Hydrogeologist
Luke J. Buckley, Database Administrator
Camela A. Carstarphen, Assistant Research Hydrogeologist
Jeremy Crowley, Assistant Research Hydrogeologist
Peggy Delaney, Program Administrator for Data Preservation–Mining Archives
Terence E. Duaime, Associate Research Professor, Hydrogeologist
Colleen Elliot, Associate Research Professor, Geologist
Alan English, Associate Research Professor, Hydrogeologist
John Foley, Museum Assistant
Phyllis Hargrave, Assistant Research Professor, Geologist
Gary Icopini, Senior Research Professor, Hydrogeologist
Stacey Konda, GWIC Lab Manager
Stanley Korzeb, Research Professor, Economic Geologist
John I. LaFave, Research Professor, Hydrogeologist, Program Manager–Ground Water Assessment Program
Jeffrey D. Lonn, Associate Research Professor, Geologist
James Madison, Associate Research Professor, Hydrogeologist
Bulbul Majumder, Software Engineer
Donald C. Mason, Research Specialist
Catherine McDonald, Associate Research Professor, Geologist
Thomas Michalek, Senior Research Professor, Hydrogeologist
Jesse Mosolf, Assistant Research Professor, Geologist, Rock Lab Manager
Todd Myse, Assistant Research Professor, Hydrogeologist
Mike Richter, Research Specialist
Leonard Rinehart, Research Specialist
James Rose, Assistant Research Professor, Hydrogeologist
Anthony Roth, Library Technician
Kaleb Scarberry, Associate Research Professor, Geologist
Deborah Smith, Professional Scientist, Seismic Analyst
Dean Snyder, Professional Scientist, Hydrogeologist
Michael C. Stickney, Director Earthquake Studies Office, Research Professor, Geologist
Mary Sutherland, Assistant Research Professor, Hydrogeologist
Susan M. Vuke, Associate Research Professor, Geologist
Kirk Waren, Senior Research Professor, Hydrogeologist
Mark Wolfram, Professional Scientist

Billings Office

Simon Bierbach, Research Assistant
Kevin Chandler, Professional Scientist, Hydrogeologist
Teresa Donato, Research Assistant
Jay Gunderson, Research Professor, Geologist
Shawn Kuzara, Assistant Research Professor, Hydrogeologist
Elizabeth Meredith, Associate Research Professor, Hydrogeologist
Jon C. Reiten, Research Professor, Hydrogeologist
Clarence Schwartz, Groundwater Specialist
John Wheaton, Senior Research Hydrogeologist

Retirees

Robin McCulloch, *Mining Engineer*
Charlotte McKenzie, *Administrative Assistant*

COMMITTEES

The Montana Bureau of Mines and Geology endeavors to provide sound scientific maps and reports for use by many segments of society. An important component of our activities is the decision process to determine topics and geographic areas of our research; advisory groups and steering committees are critical to that process. The MBMG gratefully acknowledges the many individuals and agencies who participate on these committees.

Advisory Committees

Ground Water Assessment Program and Ground Water Investigation Program Steering Committee

VOTING MEMBERS

Mr. Troy Blanford, Natural Resource Information System, MT State Library
Ms. Emily Erich, MT Department of Agriculture
Mr. Russell Levens, Department of Natural Resources and Conservation
Mr. Eric Regensburger, Department of Environmental Quality

EX OFFICIO MEMBERS

Mr. Jeff Baumberger, U.S. Bureau of Reclamation
Mr. Peter Bierbach, Bureau of Land Management
Mr. Scott Cooney, Governor's appointee – Development Representative
Dr. Stephan Custer, Montana University System
Mr. Tad Dale, Governor's appointee – Industrial Water Users
Mr. Jason Gildea, U.S. Environmental Protection Agency
Mr. James Halvorson, Oil & Gas Conservation Division
Ms. Jane Holzer, Montana Salinity Control Association, Governor's appointee – Conservation Organization
Mr. John Kilpatrick, U.S. Geological Survey
Mr. Joe Kolman, Environmental Policy Office
Mr. Tom Patton, Montana Bureau of Mines and Geology
Mr. Walt Sales, Governor's appointee – Agricultural Water Users
Mr. Steve White, Montana Association of Counties Appointee
Mr. Robert Wintergerst, USDA Forest Service Region 1 RO

Big Horn Conservation District Range tour of a coalbed-methane field, MBMG.

State Map Advisory Committee

Dr. Stephan Custer, Montana State University
Mr. Steven J. Czehura, Montana Resources
Mr. Michael Garverich, Natural Resources Conservation Service
Mr. James W. Halvorson, Montana Board of Oil and Gas Conservation
Dr. Marc Hendrix, The University of Montana
Ms. Teresa Kinley, MT Dept. of Natural Resources & Conservation
Mr. Chad Lee, MT Dept. of Agriculture
Ms. Bonnie Lovelace, MT Dept. of Environmental Quality
Mr. Seth Makepeace, Confederated Salish and Kootenai Tribes
Mr. Patrick Pierson, U.S. Forest Service
Ms. Joanna Thamke, U.S. Geological Survey
Mr. David Williams, Bureau of Land Management
Mr. Robert Wintergerst, US Forest Service

Yellowstone Controlled Ground Water Area Technical Oversight Committee

Dr. Steve Custer (chair), Montana State University (retired)
Mr. John Kilpatrick, US Geological Survey
Mr. Russell Levens, Department of Natural Resources and Conservation
Mr. Marvin Miller, Montana Bureau of Mines and Geology
Mr. David Susong, USGS for National Park Service

Data Preservation Committee

Ms. Ann St. Clair, Montana Tech
Ms. Mitzi Rossillion, Butte–Silver Bow Archives
Mr. Dave Frank, U.S. Geological Survey
Mr. Ted Antonioli, Consultant Geologist

The MBMG thrives on its interaction with citizens and agencies throughout Montana. Serving on various advisory committees and boards gives us an opportunity to learn about many issues facing the State and provide information on quite a range of topics.

Committees on which MBMG staff serve:

Acid Drainage Technology Initiative—Metal Mining Sector
State Water Plan Basin Advisory Committees
Board of Environmental Review
Butte Mine Flooding Public Education (Pit Watch)
Coalbed Methane Protection Program
DNRC Technical Advisory Council on Coalbed Methane
Future Fisheries
Montana Board of Water Well Contractors
Montana Mining Association
Montana Section of the American Water Resources Association
Montana Water Center
National Geologic and Geophysical Data Preservation Committee
Sheridan County Water Reservation Technical Advisory Committee
Tobacco Root Geological Society
Watershed Coordination Council
Western States Seismic Policy Council
Williston Area Aquifer Models Consortium
Yellowstone TOC
Yellowstone Volcano Observatory

MBMG GRANTS AND CONTRACTS

IN EFFECT DURING THIS BIENNIUM

Blacketter, D., *Natural Resources Building Geothermal Investigation*, US Dept. of Energy

Bobst, A., *Boulder River Valley Groundwater,* Jefferson County

Chandler, K., *Montana Water Center Modeling ET,* Montana Water Center

Delaney, M., *National Geological & Geophysical Data Preservation Program: Phase IV*, US Geological Survey

Delaney, M., *National Geological & Geophysical Data Preservation Program: Phase V*, US Geological Survey

Duaime, T., *Agricultural Practices Used in Source Control of AMD Problems in Central Montana (Belt-Anaconda Mine)*, MT Dept. of Environmental Quality; US Natural Resource Conservation Service

Duaime, T., *Evaluation of Arsenic Sources in Groundwater, Upper Deer Lodge Valley, MT,* Atlantic Richfield Company

Duaime, T., *Anaconda Regional Water, Waste and Soils Stormwater Monitoring,* MT Dept. of Justice

Duaime, T., *Buffalo Gulch Storm Water,* Atlantic Richfield Company

Duaime, T., *Butte Mine Flooding Consent Decree Monitoring*, MT Dept. of Environmental Quality

Duaime, T., *Natural Resource Damage, Upper Clark Fork River,* MT Dept. of Justice

Duaime, T., and Icopini, G., *Rocker Timber Framing,* MT Dept. of Environmental Quality

Duaime, T., and Berzel, M., *Crystal & Bullion Mines Water Quality and Adit Discharge Monitoring*, MT Department of Environmental Quality; US Environmental Protection Agency

Duaime, T., and Gerbrandt, H., *Review of Institutional Controls/ Land-Use Options at the Mouat (Columbus, MT) Superfund Site*, MT Dept. of Environmental Quality

Duaime, T., and Icopini, G., *Anaconda Regional Water, Waste and Soils, Long-Term Groundwater Monitoring,* Atlantic Richfield Company

Duaime, T., and Icopini, G., *Long-Term Groundwater Monitoring at the Mouat (Columbus, MT) Superfund Site*, MT Dept. of Environmental Quality

Duaime, T., and Tucci, N., *Butte Priority Soils Groundwater Evaluations*, Atlantic Richfield Company

Gunderson, J., *National Coal Resource Data System, Compilation, Collection and Correction of Coal Resource*, US Geological Survey

Gunderson, J., *National Coal Resource Data System,* US Bureau of Land Management

Icopini, G., *National Geothermal Data System*, Arizona Geological Survey; Dept. of Energy

McCulloch, R., *Geologic Resources and Mineral Potential,* US Bureau of Land Management

McDonald, C., and Vuke, S., *STATEMAP FY13*—Funded through the National Cooperative Geologic Mapping Program, US Geological Survey

McDonald, C., and Vuke, S., *STATEMAP FY14*—Funded through the National Cooperative Geologic Mapping Program, US Geological Survey

McGrath, S., *Montana Pole Superfund Site Remedial Action*, MT Dept. of Environmental Quality

Meredith, E., *Coalbed Methane Investigation*, Treasure County CD

Meredith, E., *Eastern Montana Coal Lands Ground Water Evaluation,* US Bureau of Land Management

Meredith, E., *Quantification of Coal-Aquifer Baseflow in Montana Rivers Using Carbon Isotopes*, MT Water Center, MSU; US Geological Survey

Meredith, E., and Wheaton, J., *Montana Regional Coalbed Methane Groundwater Monitoring Program*, Big Horn CD; MT Dept. of Natural Resource Conservation

Metesh, J., *Mineral Material Inventory,* US Forest Service

Metesh, J., *Yellowstone Controlled Ground Water Area Monitoring Program,* National Park Service

Metesh, J., *Yellowstone National Park Database Administration,* National Park Service

Patton, T., and Blythe, D., *Natural Resources Conservation Service Technical Services: Stock Water Supply Location and Flowing Well Rehabilitation Reports*, US Natural Resource Conservation Service

Reiten, J., *Eastern Roosevelt County;* Eastern Roosevelt County CD; MT Dept. of Natural Resource Conservation

Reiten, J., *Fox Hills/Hell Creek Aquifer Model,* Idaho National Laboratory

Reiten, J., *Remediation of Hailstone Reservoir on Hailstone National Wildlife Refuge*, US Fish & Wildlife Service

Reiten, J., *Results of Water Quality Assessment, Clear Lake Aquifer,* Sheridan County CD; MT Dept. of Natural Resource Conservation

Reiten, J., and Chandler, K., *Irrigation Potential of Ground Water Underlying the Lower Yellowstone Valley in Richland County*, Richland County CD; MT Dept. of Natural Resource Conservation

Reiten, J., and Chandler, K., *Modeling Aquifer Response to Urban Sprawl, West Billings Area, Montana,* Yellowstone CD; MT Dept. of Natural Resource Conservation

Reiten, J., and Chandler, K., *Rock Creek*, Carbon County CD; MT Dept. of Natural Resource Conservation

Stickney, M., *Flathead Seismic Monitoring System*, Confederated Salish Kootenai Tribes

Stickney, M., *Montana Regional Seismograph Network*, US Geological Survey

Stickney, M., *Operation of the Montana Regional Seismograph Network*, US Geological Survey

Stickney, M., U*pgrade of Selected Montana Regional Seismograph Network Stations*, US Geological Survey/ARRA

Tucci, N., *Butte Area One Fingerprint Study*, MT Dept. of Justice

Tucci, N., *Butte Priority Soils Groundwater Evaluation and Technical Assistance,* MT Dept. of Environmental Quality; US Environmental Protection Agency

Photo by Kaleb Scarberry, MBMG

MBMG
Montana Bureau of Mines and Geology

Contact us:

Butte
1300 W. Park Street
Butte, MT 59701
Phone: 406-496-4180
Fax: 406-496-4451

Billings
1300 N. 27th Street
Billings, MT 59101
Phone: 406-657-2938
Fax: 406-657-2633

This report was created and printed by Publications staff of the Montana Bureau of Mines and Geology.