# MBMG

## Montana Bureau of Mines and Geology

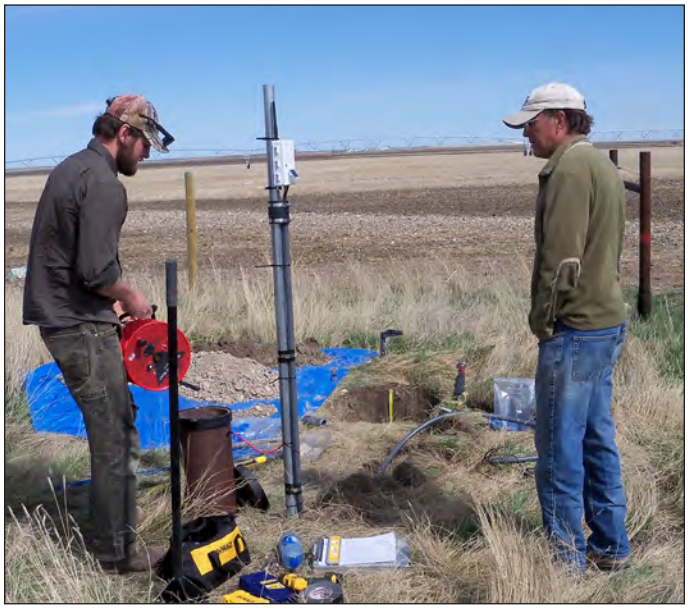
**Biennial Report of Activities and Programs**

**July 1, 2018 to June 30, 2020**

A department of Montana Technological University


*Jeff Lonn (MBMG) and Russ Burmester (IGS) work together on the map along the Idaho–Montana border.*

*Joel Dietrich, a Montana Tech student studying for his MS in Geoscience with a focus in Geology. Joel worked for the MBMG this summer as a mapping geologist in the Elkhorn Mountains southeast of Helena, MT. The mapping is part of a national effort from the U.S. Geological Survey called the Earth Mapping Resources Initiative (Earth MRI).*



*Brett Heitshusen (Montana Department of Agriculture) and Don Mason (MBMG) install a real-time Mesonet station near Choteau. The real-time groundwater-level data provide up-to-date, high-frequency measurements.*

*Cover photos:*

*Top front photo by Ron Breitmeyer, MBMG. Bottom front photo by Denise Herman, MBMG. Back photo by Colleen Elliott, MBMG.*

# 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.

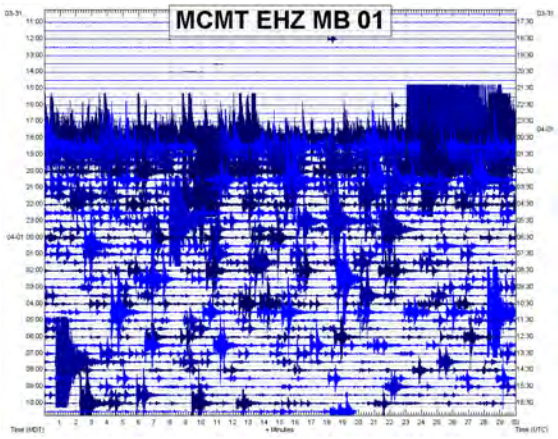
**Our mission is to provide information for the sound use of Montana's geological and water resources. Our vision is to be Montana's lead source of geologic and water information.**

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. We are housed on the campus of Montana Technological University and maintain a fully staffed office in Billings.

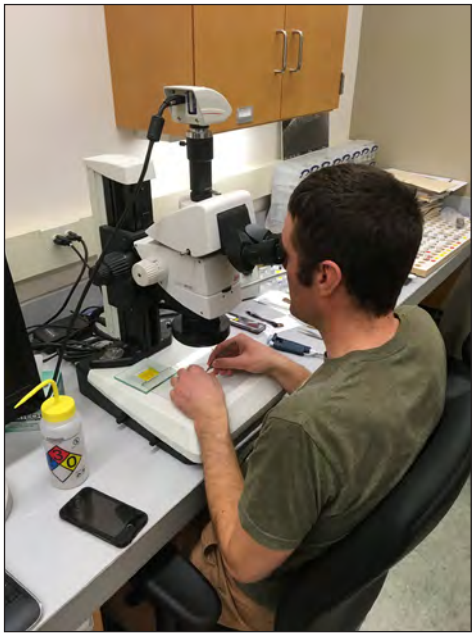
Our geologic mapping program, supported by both State and competitive Federal funding, continues its work on the complex geology of western Montana; we released several new maps, including collaborative maps with the Idaho Geologic Survey. A new program hosted by the U.S. Geological Survey, the Earth Mineral Resource Initiative, provides funding for mapping and assessment of critical minerals—a task for which Montana and the MBMG are well suited. Funding has been secured for mapping economic mineral deposits that are primarily in western Montana; several publications based on this new work are in planning.

As is our tradition, the MBMG publishes high-quality, reviewed publications for both scientists and the public. In the 2018–2020 biennium, we published 44 maps and reports and an additional 54 structure contour maps, legacy maps constructed by Bob Bergantino. We continued with our new digital publications ("story maps") in 2019 with MBMG Digital Publication 2, *Montana's Seismic Hazards*, by Yiwen Li and Mike Stickney, and in 2020 with MBMG Digital Publication 3, *Digital Structure Map of the Eagle Formation, Central and Eastern Montana,* by Jay Gunderson. You can view them through our publications catalog on our website.

The MBMG has several new members replacing retirements in geology and hydrogeology; a complete list of MBMG members is included in this report. Nancy Favero retired in July 2018 after 28 years of service in our Publications Office; among many other things, Nancy was our original webmaster. Peggy Delaney retired in December 2018 after 13 years of service, finishing as our Mine Archives Data Preservationist. Kirk Waren, a hydrogeologist, retired in December 2018; Kirk had a 31-year career, with the last 12 being with the MBMG. Phyllis Hargrave, a geologist with several programs and projects over the years, retired in May 2020 after 25 years of service to the MBMG. John Wheaton, a hydrogeologist in our Billings Office and inaugural Program Manager of the Ground Water Investigation Program, retired in July 2020 after 32 years of service to the MBMG.




*MBMG seismogram of the Stanley, Idaho 6.5 magnitude earthquake March 31, 2020.*



*MBMG lab manager and mapping geologist Jesse Mosolf uses the binocular microscope to select zircon grains for age dating.*

# UUNO SAHINEN AWARD

The Silver Medallion Award is given annually by the Montana Bureau of Mines and Geology in memory of 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 2019 Uuno Sahinen Award was presented to Jack Warne at the university's commencement ceremony on Saturday, May 4, 2019.**

Jack Warne was born in Honolulu, Hawaii in 1929, and graduated from high school there. He went on to Stanford University where he received a bachelor of science degree in 1951 and a master's degree in Geology in 1952, both from Stanford's School of Mineral Science. After his discharge from the U.S. Air Force in 1953, Jack went to work for Shell Oil Company doing oil and gas exploration in Denver, Houston, and Billings. In 1959, he left Shell and hung out his shingle as a consultant/independent geologist in Billings, Montana.

Jack and his wife, Bonnie Warne, have been married for 36 years. Both were married before, and have six children between them. While some consider him retired, Bonnie says the mess of maps in his home office belies this. He once said, "One lifetime is not enough for a geologist."

Early in his career, Jack participated in a geology study group in Denver composed of researchers from major oil companies, the Colorado School of Mines, and the Colorado Geological Survey; he later organized a similar study group in Billings. As Chair of Continuing Education for the Montana Geological Society in the 1970s, he brought nationally recognized experts to conduct 2-day workshops in Billings covering new developments in structural geology, oil and gas source rocks, and sedimentation.

Through most of his professional life he focused on exploration of oil and gas prospects, mainly in the Rocky Mountain states, and his work led to the development of more than 20 oil and gas fields in five states. Many of his major prospects were in lightly explored areas with little drilling, aiming for high-risk giant fields; this pioneer drilling contributed to the knowledge of structure, stratigraphy, and source rocks in remote areas.

Although most of his work is in confidential exploration reports and maps, Jack authored several field guides and road logs and has led many field trips published by the Montana Geological Society, the Tobacco Root Geological Society, and the Rocky Mountain Section of the American Association of Petroleum Geologists. He is still an active member of the American Association of Petroleum Geologists, Rocky Mountain Association of Geologists, and Montana Geological Society. He is a past president of the Tobacco Root Geological Society and past member of the Geological Society of America and American Institute of Professional Geologists.

**The award is normally presented at the university's commencement ceremony in May, but due to COVID-19 during 2020, will be presented at a later date. Plans are to present it at commencement 2021.**

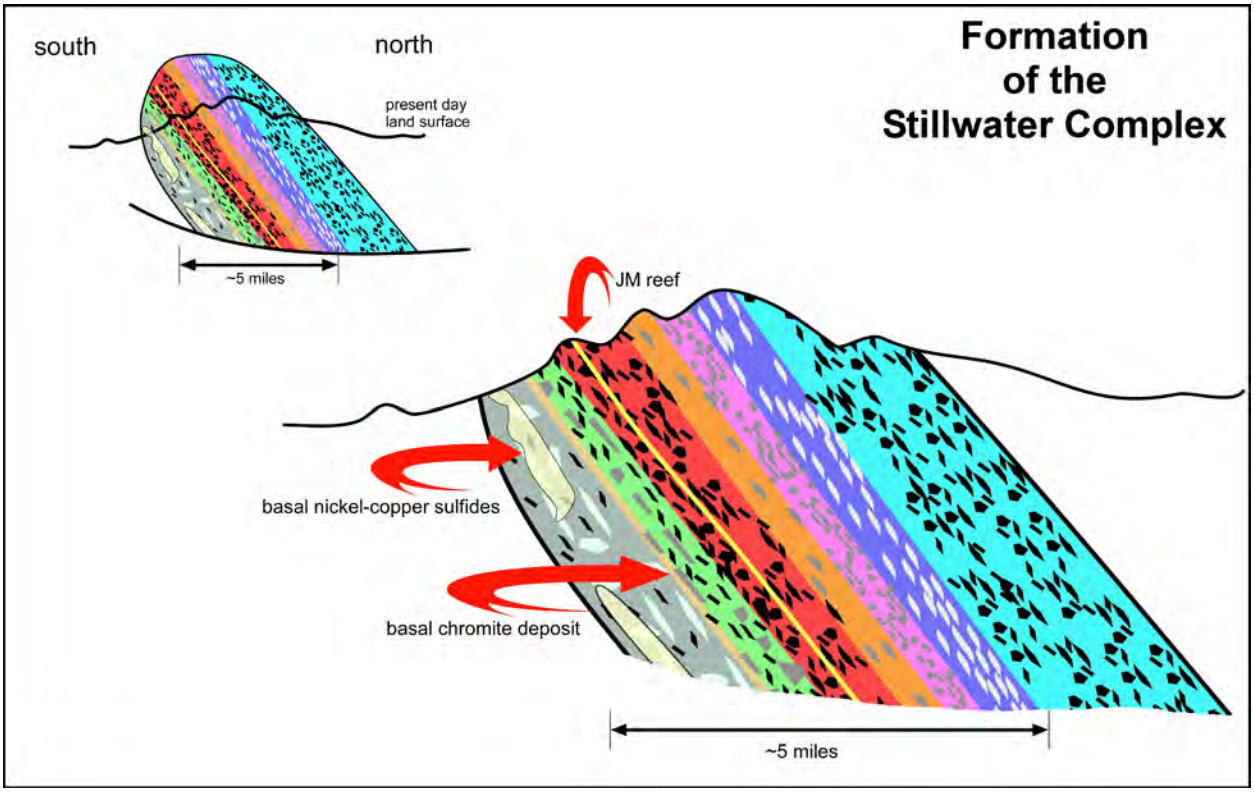
The 2020 Uuno Sahinen award was presented to Stan Todd.

Stan earned his bachelor's and his master's degrees in Geology at Montana State University in 1969. His master's thesis was based on his work in the Tom Miner Basin adjacent to the Beartooth Range, which hosts the Stillwater Complex. In 1973, he received his doctorate in geology from Washington State University. His dissertation described Geology and Mineral Deposits of the Spirit Pluton in Washington.

Shortly after receiving his PhD, Stan was hired by a Johns Manville exploration geologist to log the first drill core samples of what would be later named the J-M Reef, the palladium (Pd) and platinum (Pt) bearing horizon of the Stillwater Complex in the Beartooth Mountains of south-central Montana.

This work supported early efforts to map the world-class platinum–palladium deposit, and Stan was invited to be a guest researcher at the Carnegie Institute to further explore the Stillwater Complex petrology and mineralization. His research produced several papers published in Carnegie Institute Year Book, Geologic Society of South Africa, and Economic Geology. These papers became the "bible" by which the J-M Reef exploration, mine development, and mining geology staff worked.

Through the late 1970s and into the early 1980s, Stan was either the chief exploration geologist or among the group of chief geologists directing the Johns Manville exploration program. The objectives of the program were to locate, map, and sample surface exposures of the J-M Reef, stake discovery claims, and core drill through the J-M Reef to validate the claimed areas. Stan was also an international exploration geologist for industrial minerals, including diatomaceous earth and perlite for Johns Manville in the U.S., Africa, South America, Australia, and other locations. He also visited and toured many of the world's platinum exploration and mining operations, such as the Bushveld Complex in South Africa and the Norilsk Nickel operations in Russia. Stan, along with other Manville geologists, evaluated many similar ore bodies within the U.S. In 1983, Stan moved to the Stillwater Mine project at Nye, Montana as a lead geologist until 1987, then continued exploration and property assessment work for industrial minerals deposits for Johns Manville. Stan compiled all of Manville's perlite and diatomite exploration information and wrote summaries of selected properties. He finally retired in 2000 after a 27- year career, but is still actively exploring the geology of Montana as an interest and hobby.




*An illustration of the J-M Reef.*

# GROUND WATER ASSESSMENT

Groundwater is one of Montana's greatest natural assets. In order to improve the understanding of Montana's groundwater resources, the Legislature established the Ground Water Assessment Program at the MBMG in 1991 as a means to collect, interpret, and disseminate essential groundwater information.

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 water-level measurements and water-quality samples 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.

Since 1993, the MBMG has been collecting systematic groundwater-level data from an 800+ well statewide network that covers the State's major aquifers; some wells have been regularly monitored since the 1950s. Several partners maintain local groundwater-level networks and share their data with the MBMG.

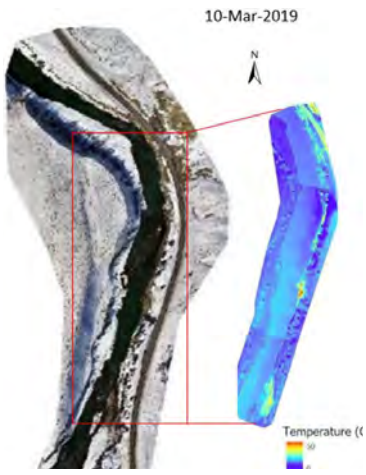
Cooperators include:

- Confederated Salish Kootenai Tribes Water Resources
- Gallatin Local Water Quality District
- Missoula Valley Water Quality District
- Lewis and Clark Water Quality Protection District
- Sheridan Conservation District
- Yellowstone Controlled Groundwater Area

The MBMG joined the National Ground Water Monitoring Network (NGWMN) in 2009, to secure federal funding opportunities for monitoring in Montana.

*Groundwater Monitoring—Getting Real (time)*

During the past biennium, the Ground Water Assessment Program forged a partnership with the Montana Department of Agriculture (MDA) and the Montana Climate Office (MCO) to provide real-time groundwater monitoring at 15 sites across Montana. The MDA is co-locating Mesonet stations next to wells that are used to monitor groundwater levels and agriculture chemicals. The Montana Mesonet is a partner-driven system of automated climate observation stations that transmit near real-time observations of weather and soil moisture to the MCO (http://climate.umt.edu/mesonet/default.php). Where located next to a well equipped with a pressure transducer, groundwater-level data are also transmitted. The raw groundwater transducer data are 'harvested' from the MCO server by MBMG's Ground Water Information Center (GWIC) every 30 minutes, converted to 'depth below ground' measurements, and loaded into the GWIC database for online viewing or download. The water levels will be 'ground-truthed' by manual measurements at least four times per year.




This interagency partnership creates sites where atmospheric, soil moisture, and groundwater data are monitored at high frequency and available online almost instantaneously. The efficiency gained through shared resources is providing unique information about the response across the hydrologic cycle to citizens, water managers, scientists, and educators.

*(L) Montana Tech graduate student Jesse Bunker packs up after a cold drone flight along the Yellowstone River. (R) A 3D and thermal orthomosaic of the LaDuke study area along the Yellowstone River about 6 miles north of Gardiner, Montana. Warm colors on the thermal orthomosaic pinpoint the location of hot springs and seeps.*

## Ground Water Characterization Program

The Characterization Program provides basic information about aquifers within specific areas as prioritized by the Ground Water Assessment Steering Committee. Characterization field staff are currently working in Lincoln and Sanders counties to assess the basin-fill and fractured-rock aquifers that supply most rural homes and several municipalities.

*Groundwater Assessment—Where hot and cold water meet, viewed from above*

The Montana Ground Water Assessment Program is committed to developing new methods and employing new technologies to assess the State's groundwater resources. A project just north of Yellowstone Park used an unmanned aerial vehicle (UAV, or "drone") to assess the extent of hot springs and seeps, and their seasonal variation in discharge to the Yellowstone River in the vicinity of LaDuke Hot Springs. An optical and thermal camera on a UAV were used to gather aerial data over a half-mile stretch of the Yellowstone River near the LaDuke hydrothermal area multiple times over the course of a year. During flights, both visual and thermal cameras took images every few seconds. The resulting mosaic of images were used to create 3D and temperature maps, allowing us to analyze changes in seep locations, river surface, and temperature.

*Groundwater Assessment—What do isotopes tell us about recharge?*

To provide insights on groundwater recharge, the Ground Water Assessment Program initiated a pilot project—the Montana Precipitation Isotope Network (MT PIN)—to assess natural variations in the stable isotope composition of precipitation in three different western Montana watersheds. Precipitation (rain and snow) from eight sites, at different elevations, is being collected monthly and analyzed for stable isotopes of water: oxygen-18 ($^{18}O$) and deuterium ($^{2}H$). Nearby surface water and groundwater are also being analyzed.

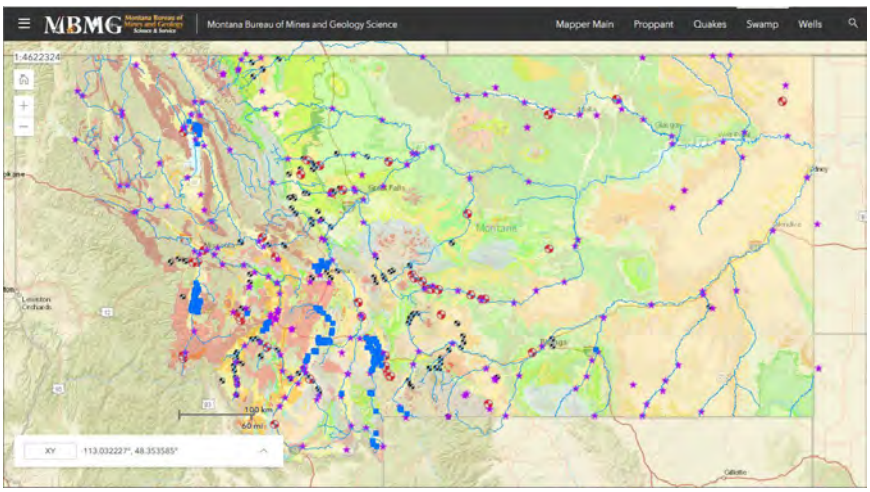
The goal is to correlate and compare the observed isotopic compositions of groundwater with precipitation and surface water to provide a better understanding of the source, timing, and rates of groundwater recharge. Cooperators on this project include the Montana Climate Office, The University of Montana Department of Geosciences, the U.S. Forest Service, the Lolo Watershed Group, the Lewis and Clark County Water Quality Protection District, the U.S. Geological Survey, and Montana Technological University.

*Montana Tech student Cory Riley collects a 'winter precipitation' sample.*

## Ground Water Information Center (GWIC)

The Ground Water Information Center (GWIC) is the repository for the State's groundwater information. The website (http://mbmggwic.mtech.edu/) provides online access to water-well logs, hydrographs that track water levels in the State's major aquifers, maps of groundwater flow systems, and water-quality reports describing groundwater conditions across the State, as well as a variety of field, chemical, and physical data.

As part of the evolving Data Center at the MBMG, GWIC provides interactive maps on the website for data visualization and map-based data retrievals for water wells, seismic activity, native proppants, and surface-water data. The Surface Water Assessment and Monitoring Program (SWAMP) mapper was developed as a joint project to store and display real-time and manual measurements of stream discharge data collected by the Department of Natural Resources and Conservation (DNRC) and the MBMG. Stream gages monitored and maintained by the USGS are also included for viewing. Currently there are 176 locations; 29 sites provide real-time discharge, stage, and temperature data.




*The SWAMP mapper shows sites where real-time and manually measured surface water data are available from MBMG, DNRC, USGS, and Gallatin Local Water Quality District.*

Building on the successful collaboration with DNRC, the MBMG and the Gallatin Local Water Quality District (GLWQD) have instituted a pilot program for other agencies to include their data in the SWAMP database. Thirteen sites from the Gallatin Valley are now included and available through the SWAMP website (https://mbmg.mtech.edu/swamp).

# GROUND WATER INVESTIGATION PROGRAM

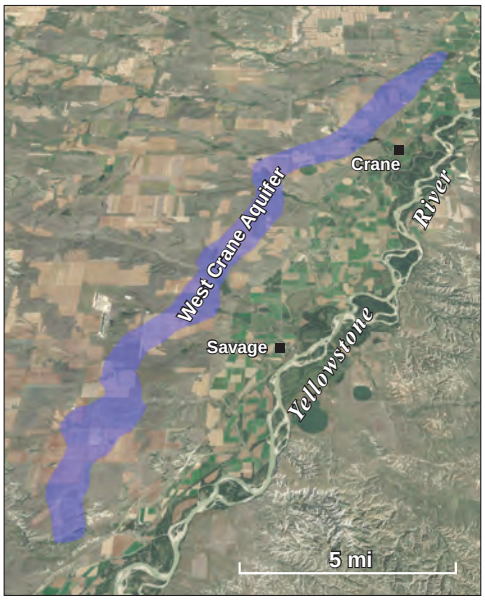
The Ground Water Investigation Program (GWIP) answers locally identified, site-specific water resource questions prioritized by the Montana Ground Water Steering Committee (MCA 85-2-525).

In Montana, groundwater is essential for safe drinking water supplies and for economic growth. In many areas of the State, groundwater is the only reliable source of water for household use and livestock. It is also used for irrigated agriculture and provides baseflow to Montana's rivers. Changing land use and demographics can alter groundwater withdrawals, stream flows, the availability of irrigation water, and the health of aquatic ecosystems.

Montanans are increasingly concerned about how best to plan for future water supplies, and to ensure that water policy is based on the best available science. Future water management should reflect the increasing value of Montana's water resources and must address decisions about competing needs for water.

## Current research questions include:

- Effects of changing irrigation methods on groundwater recharge and surface-water baseflow
- Identifying natural and manmade influences on stream dewatering
- Aquifer and stream response to changing land use from irrigated agriculture to residential development
- Hydrogeologic viability of replacing surface-water diversions with irrigation wells
- Groundwater sustainability in response to increasing residential, irrigation, and commercial demands
- Changes in water quality due to increasing subdivisions
- Viability of developing buried river channel aquifers
- Impact on stream flow of increasing groundwater withdrawals




*GWIP hydrogeologists, through drilling, identified the extent of the West Crane buried alluvial aquifer. The aquifer is capable of well yields up to 1,500 gpm.*

## The 2018–2020 Biennium

Three new GWIP project start-ups:

- *Musselshell River, Musselshell, and Petroleum Counties*—Investigate the relationship among groundwater, irrigation, and high salinity in the Musselshell River.
- *East Flathead Valley, Flathead County*—Evaluate the effects of pumping on surface water from the shallow and deep aquifer systems.
- *Upper Gallatin Corridor, Gallatin County*—Evaluate water availability and quality, as growth in the Big Sky area continues to increase.

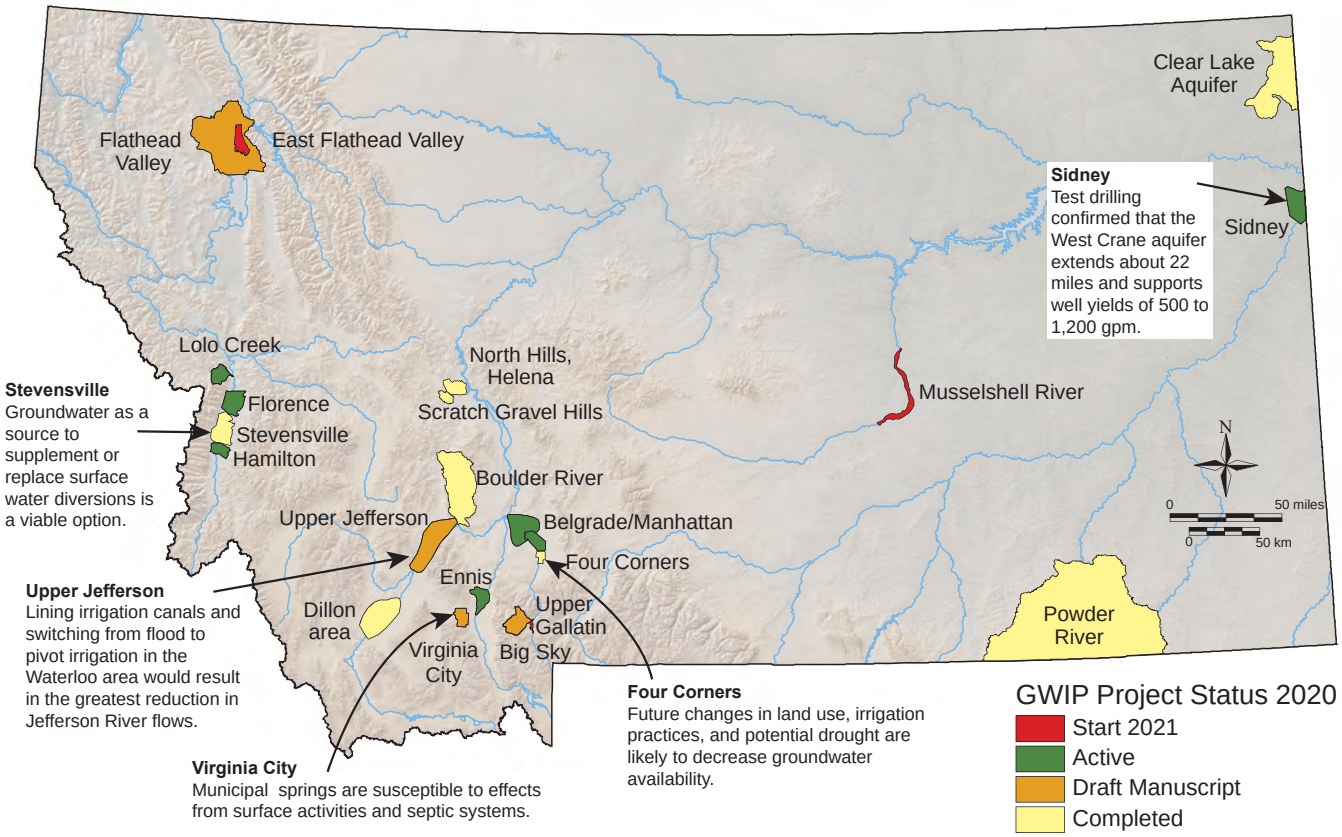
## Program Products

GWIP products are designed to provide a more detailed understanding of the groundwater and surface-water systems. Results are presented in public forums, inquiries, conferences, and published reports. The information has been used in water-right permit decisions, water-resource development, and county planning to make informed water management decisions. Program products include:

- ✓A report on the hydrogeologic system and responses to current and anticipated stresses
- ✓Groundwater models available to users that simulate specific hydrogeologic features and stress responses
- ✓ A comprehensive set of hydrogeologic data for each project are permanently available online through the Ground Water Information Center (http://mbmggwic.mtech.edu/)

## Program Status

To date, over 85 projects have been nominated and prioritized by the Ground Water Steering Committee. The map below shows completed and current project areas.




## Publications Released in 2018–2020

- Hydrogeologic Investigation of the Four Corners Area, Gallatin County, Montana, MBMG 735
- Hydrologic Investigation of the Upper Jefferson River Valley, Whitehall groundwater modeling report, RI 27
- Aquifer Tests in the Upper Jefferson Valley, MBMG 727
- Virginia City, Montana Aquifer Test, MBMG 726
- West Crane Buried Valley Aquifer: A Hidden Resource, IP 13
- Hydrogeologic Investigation of the Stevensville Study Area Ravalli County, MBMG 733
- South Medicine Lake area of the Clear Lake Aquifer: Groundwater Model Report, MBMG 720

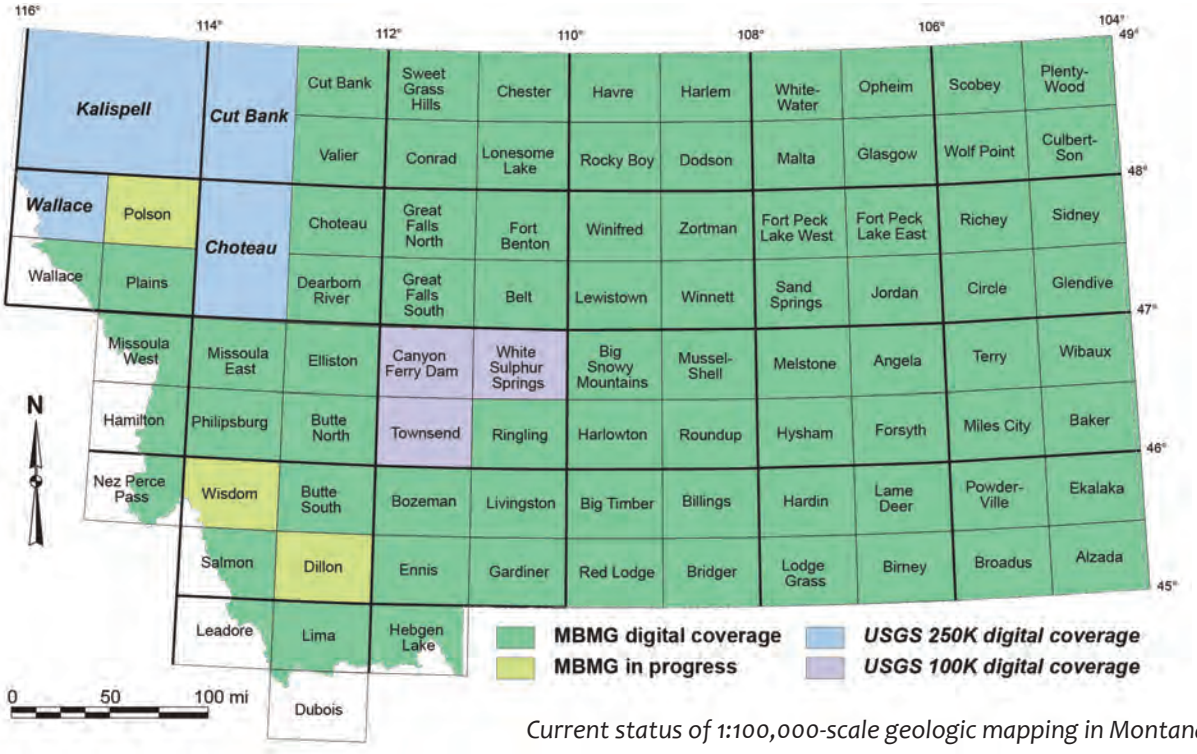
*Jim Berglund, a hydrogeologist for GWIP, is collecting drill cuttings to define the subsurface stratigraphy in the Flathead Valley.*

# GEOLOGY PROGRAMS

## STATEMAP Geologic Mapping

Geologic maps provide essential information for managing Montana's water, land, mineral, and energy resources. During the past biennium, the Montana Bureau of Mines and Geology published eight new geologic maps based on fieldwork conducted through the STATEMAP Program, a component of the National Cooperative Geologic Mapping Program. Funding for STATEMAP is awarded by the U.S. Geological Survey through a competitive grant process that requires matching dollars from the State and completion of all funded maps within 1 year.

Map areas are prioritized by a State Mapping Advisory Committee that represents Montana industries and universities, as well as Federal, State, and Tribal agencies. The Advisory Committee's main priority is to complete geologic maps of all 30' x 60' quadrangles in Montana. The MBMG finished mapping in eastern and central Montana in 2014 and has since focused on southwestern Montana. During the past biennium, the MBMG completed and published geologic maps of the Salmon, Elliston, and Butte North 30' x 60' quadrangles. Mapping continues in the Wisdom and Dillon 30' x 60' quadrangles, and should be finished by 2023.




*Current status of 1:100,000-scale geologic mapping in Montana.*

The Advisory Committee's second priority is detailed maps that focus on significant geologic issues, transportation corridors, or on areas where population development is occurring or anticipated. Five geologic maps of this type were published during the past biennium. Preparation of 21 other large-scale maps is underway. Several of these maps are joint projects with the Idaho Geologic Survey as part of ongoing work to match the geology across our common border. All published STATEMAP products are available for free download from the MBMG website, http://www.mbmg.mtech.edu/.

In 2020, the USGS provided supplemental funding through the STATEMAP program to help states convert existing and future geologic maps to a nationally consistent digital geodatabase. The MBMG is using the majority of the additional funding to update and convert our 2007 Geologic Map of Montana to the new standard.

*The Treasure talc mine in the Ruby Mountains, east of Dillon, where MBMG geologists are currently mapping Precambrian rocks that host world-class talc deposits.*

# Geologic Hazards Program

The Geologic Hazards program, initiated by MBMG geologists in 2018, aims to provide high-quality information on landslides, potentially active faults, and earthquakes. The program's first goals are updating the map and database of active faults and creating a landslide map and database for Montana. Faults are considered active if they have produced an earthquake during the Quaternary Period (past 2.58 million years) and have the potential to generate a future earthquake. The existing map of active faults in Montana contained 116 faults and was published in 2000. The current version, updated by the MBMG, includes 608 faults and is undergoing review to determine which may be potentially active. The MBMG will continue to update the map and database as new geologic mapping and other data become available. The active fault database will be used to prioritize future investigations of active faults and to help assess seismic hazards throughout the State.

The Hazards Program has also been successful in acquiring funding for field investigations of active faults. In 2019, the MBMG investigated an active fault located about 13 miles northeast of Butte, near Interstate 15. The project involved trenching across the fault, interpreting the geology exposed within the trench, and collecting samples to help constrain the age of faulting. Preliminary results indicate deformation associated with the fault occurred sometime after 11,200 years ago—recent enough to indicate an active fault. The trenching project was the first by MBMG in over 33 years, yet is the type of field-based project needed to systematically collect and disseminate data critical for assessing earthquake risk in Montana. Our work on the Bitterroot fault, with funding from the U.S. Geological Survey's National Earthquake Hazards Reduction Program, also continues. In 2020, over 30 samples were collected that will help determine the average slip rate across the Bitterroot fault and thus how frequently large, potentially damaging earthquakes may occur there.

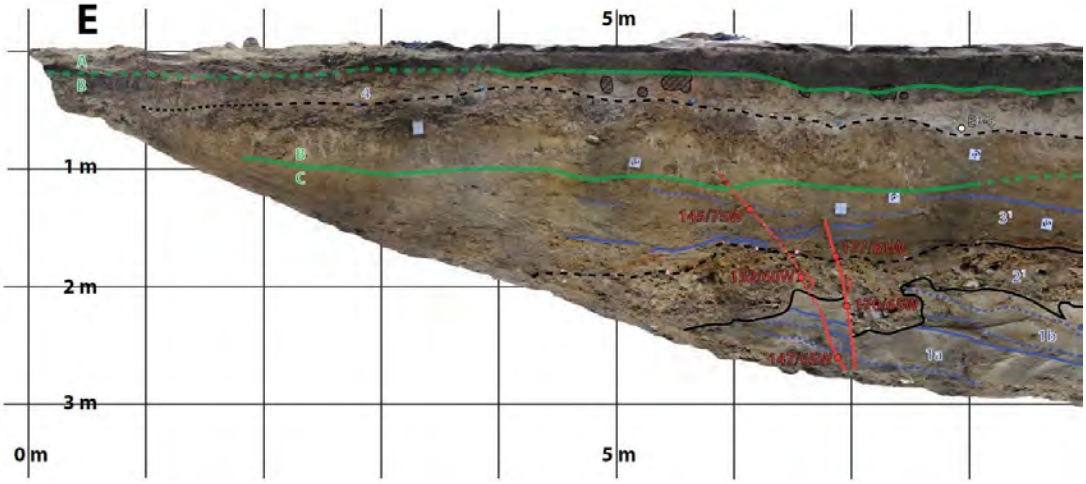



*Photo showing cross section of sediments exposed in the Elk Park earthquake trench. Red lines are small faults that offset layers exposed near the bottom of the trench. Green, blue, and black lines differentiate geologic layers.*

Two additional geologic hazard projects are currently underway. In 2019, the MBMG obtained funding to create a statewide map showing liquefaction susceptibility. Liquefaction occurs when young, unconsolidated, water-saturated sediments at or near the ground surface lose their strength in response to seismic shaking. Liquefaction can contribute to damage of buildings and other infrastructure during earthquakes. The regional-scale liquefaction map will show areas of "very high" to "very low" susceptibility and is a joint project between the MBMG and Geological Engineering faculty at MT Tech. The second project, funded in 2020, will use newly acquired LiDAR data for Jefferson and Deer Lodge Counties to identify and map landslides and potential active faults, improving existing geologic mapping in those areas. Both projects, using funds administered by the Montana Department of Emergency Services (DES), will be used in geologic hazard assessment, emergency planning, earthquake mitigation and preparedness, and public education.

*Yann Gavillot sampling a glacial boulder along the Bitterroot Fault. The sample is one of several that will be used to determine the average slip rate across the Bitterroot fault.*

# ENVIRONMENTAL HYDROGEOLOGY

Mineral extraction in Butte and the surrounding area dates to the 1860s and continues today. Over the past 150 years, mining methods have changed and evolved to the development of large-scale open pit mines. The Berkeley Pit grew out of the expansion of underground mining as a means to extract low-grade ore in a more economic manner not suitable for underground mining. The Berkeley Pit and associated underground workings are part of the larger Clark Fork Basin Federal Superfund Complex, and the MBMG has been actively involved with groundwater and surface-water monitoring and sampling for the past 37 years.

The MBMG has conducted over 70 sample events on the Berkeley Pit since 1983, collecting more than 250 discrete samples. Results of those sample events have been used to track the changes in water chemistry and physical parameters of the pit. While minor changes in concentrations of various elements have occurred throughout the period of monitoring, the most significant have occurred recently. The most notable to the casual observer is the visible change in water color, seen in figures 1 and 2. For many years the pit water color was characterized by a dark-brownish appearance (fig. 1) and more recently (fig. 2) by a vibrant green.

*Figure 1. Berkeley Pit, 2004.*

*Figure 2. Berkeley Pit, 2020.*

Biannual (spring and fall) water sampling and profiling of the Berkeley Pit's water were conducted during this biennium, and data from these sampling events help explain the visible color change. Data collected during vertical profiling show a major change in the pit's water pH from 2017 to 2020 in comparison to data collected in 2012 (representative of all previous data). Figures 3 and 4 show that pH and dissolved oxygen values increased dramatically throughout the pit's water column in 2018, 2019, and 2020 compared to the 2012 data.

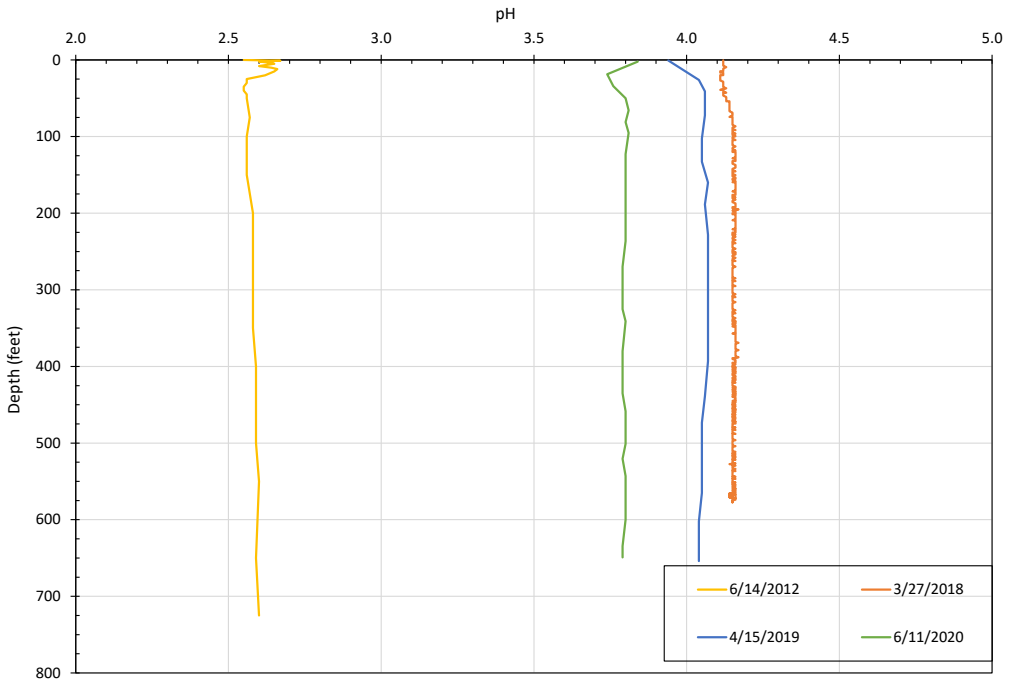



*Figure 3. Berkeley Pit pH values in 2018, 2019, and 2020 vs. 2012.*

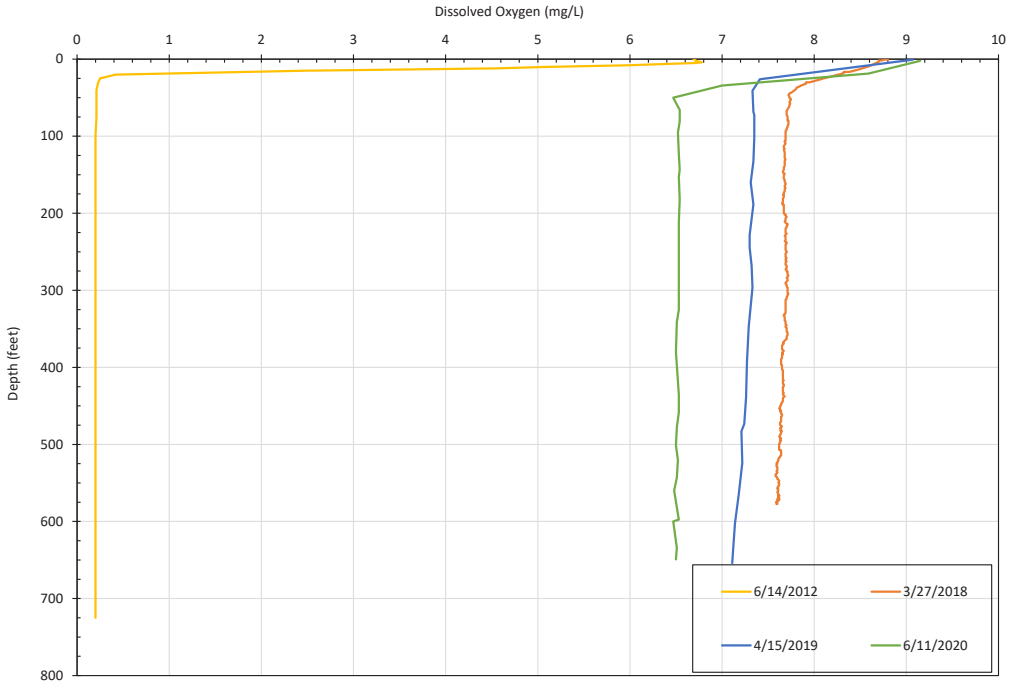



*Figure 4. Berkeley Pit dissolved oxygen values in 2018, 2019, and 2020 vs. 2012.*

Along with the noted changes in the water's pH and dissolved oxygen, there was a significant reduction in iron concentrations throughout the water column. Iron concentrations in samples collected in 2012 from the pit ranged from 211 mg/L at the surface to 264 at depth (500 ft), while concentrations in 2020 ranged from 5 mg/L at the surface to 1.5 mg/L at depth (430 ft). The increasing pH and corresponding decrease in iron are probably the result of several operational practices within the mining and water treatment operations, the most significant being the disposal of alkaline-rich sludge from the Horseshoe Bend Water Treatment Plant in the Berkeley Pit since the fall of 2003. This sludge has most likely helped rise to pH of the water, which in turn resulted in the co-precipitation of iron, reducing the concentration of iron throughout the pit water column. In conjunction with the precipitation of iron, the water color changed and became less opaque. The greenish color is likely representative of the high copper–sulfate concentrations in the pit water.

## Current Projects

- Butte Mine Flooding Long-Term Monitoring
- Basin Watershed-Acid Mine Drainage (Bullion and Crystal Mines)
- Rocker Controlled Groundwater Area
- Belt, MT Acid Mine Drainage: Groundwater Monitoring Program
- Mouat Superfund Site, Columbus, MT: Long-Term Groundwater Monitoring
- Berkeley Pit: Autonomous Sample Boat Program
- Private Well Sampling Program, Butte Controlled Groundwater Area
- Glacier–Toole Co. Public Water Supply, Arsenic and Antinomy Sources
- Beal Mountain Mine Conceptual Site Model
- Determining Surface-Water Influences on Groundwater Upper Silver Bow Drainage
- Yankee Doodle and Upper Silver Bow Creeks Monitoring
- Granite Mountain Mine Well Installation and Evaluation

# ENERGY RESOURCES

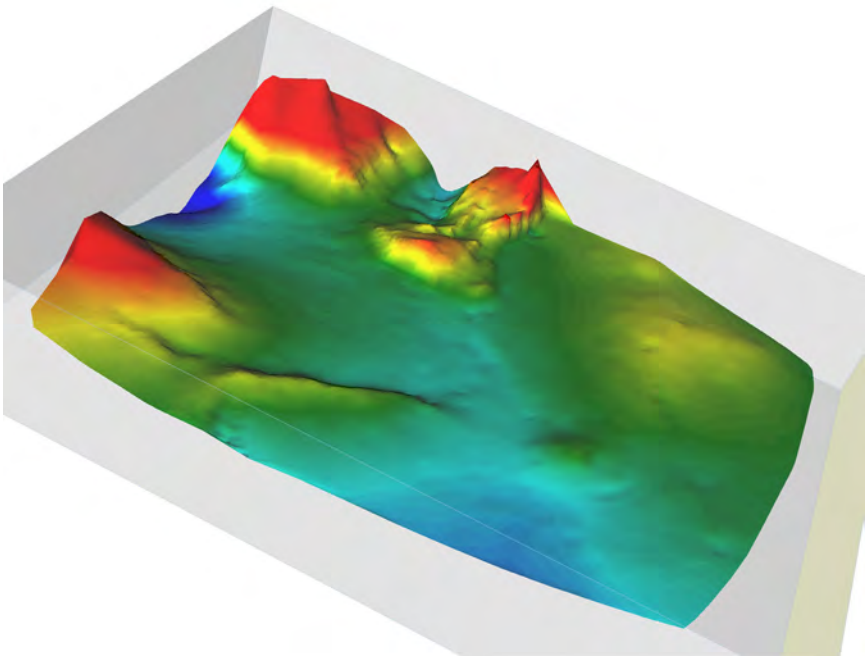
## MBMG Coal Program

Montana leads the nation with 120 billion tons of demonstrated coal reserves. Since the 1960s, the MBMG Coal Program has conducted statewide coal resource assessments and coal availability studies to determine the distribution, quantity, and quality of the State's mineable reserves. The MBMG also maintains coal stratigraphic and coal chemistry databases that are available to the public. These data were critical for a 2015 USGS reassessment of coal resources and reserves in the Powder River Basin; they are also vital to those developing and testing new coal power technologies and to those who make energy and land-use policy decisions.

Demand for coal-fired power has waned during the past decade, yet coal remains a valuable commodity for the State. Nationally, new efforts are focused on expanding and transforming the use of coal and coal-based resources to produce rare earth elements and nonfuel carbon-based products. The MBMG, in collaboration with neighboring states, is in the initial stages of evaluating our coal deposits as a potential source for rare earth elements and other critical minerals.


*Coal sampling: (left) by core and (right) by hand at the mine.*

## Subsurface Geologic Mapping



*3D visualization of Eagle Formation structure, eastern Montana.*

The MBMG has actively mapped and studied surface geology for decades. However, knowledge of the geology below ground can be just as important as our knowledge of surface geology. Subsurface geologic maps are critical for understanding geologic hazards such as faults, identifying targets for wastewater injection, managing and protecting groundwater aquifers, and exploring for petroleum and other mineral resources.

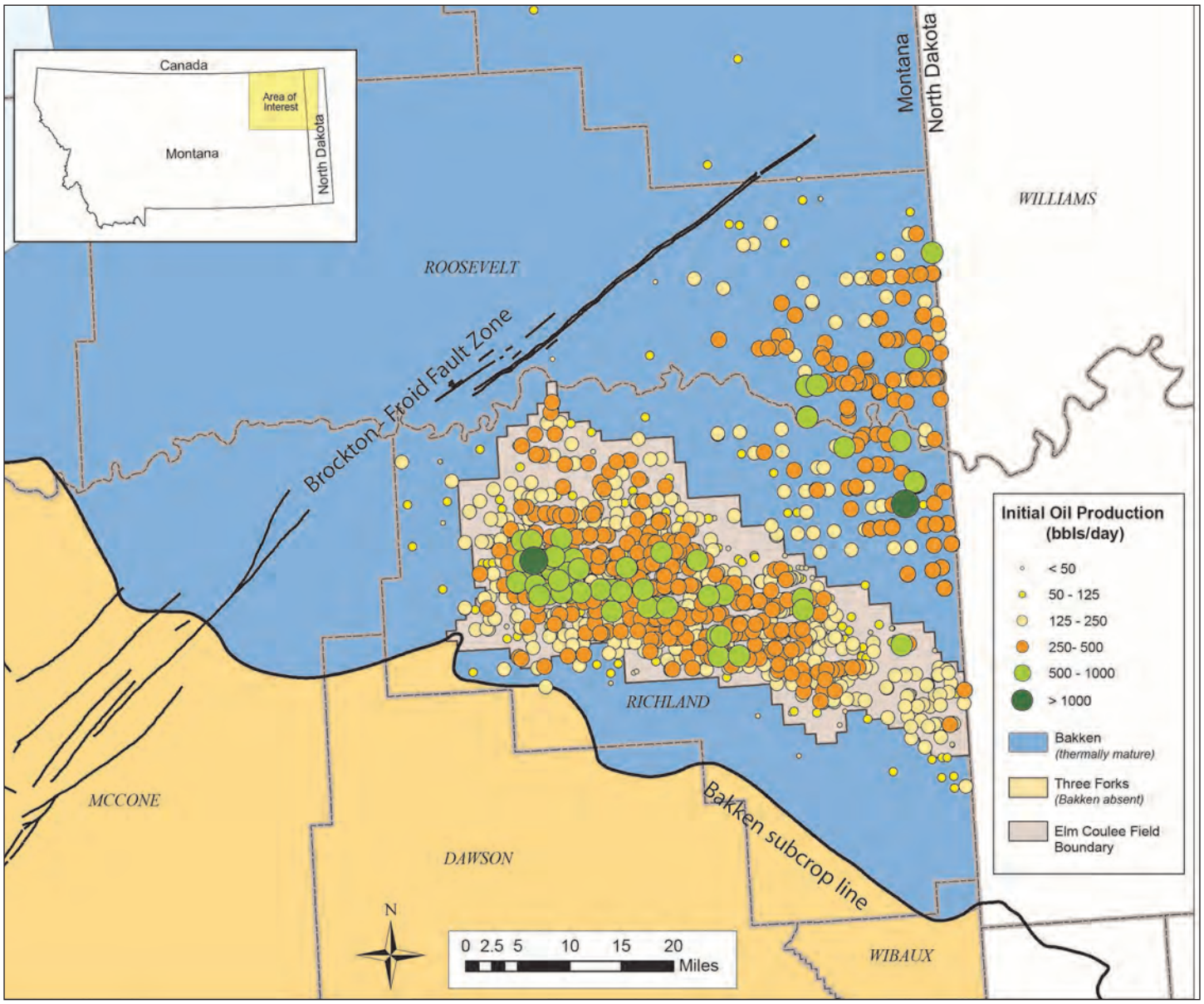
The MBMG is pursuing a multi-year effort to generate digital maps that depict structure (spatial positioning and shape) and properties (e.g., thickness, lithology) of subsurface geologic units. Digital maps are easily imported into a wide range of software applications for visualization, grid manipulation, and constructing 3D models.

## Oil and Gas Research

The Bakken–Three Forks Petroleum System in the Williston Basin is one of the most prolific continuous oil accumulations in North America, with an estimated mean of 7.4 billion barrels of technically recoverable oil resources. Because each Bakken well produces only about 10–15% of the oil in place, we must rely on enhanced oil recovery (EOR) processes that inject gas or fluids into the reservoir to mobilize and recover additional oil reserves. In 2012, the Montana Board of Oil and Gas funded a project for MT Tech and MBMG to create a geologic/reservoir model of Elm Coulee field and simulate the field's behavior and performance under varying EOR conditions.

The project was expanded in 2018 to include an area northeast of Elm Coulee that has different geological characteristics and higher water production during primary recovery. Understanding reservoir behavior prior to onset of EOR will improve reservoir management, increase ultimate oil recovery, and extend the life of Elm Coulee field and Bakken wells outside of Elm Coulee field. Reservoir simulations suggest that an additional 20% of original oil in place may be recoverable using natural gas flooding at Elm Coulee.

In 2020, the MBMG published a study of Bakken well initial production (IP) rates. Horizontal wells completed in the Bakken Formation exhibit a wide range in productivity and IP rates are a common and convenient way to identify "good wells" versus "poor wells." Initial production rates can also serve as a guide to identifying highly productive areas (i.e., "sweet spots") in the Montana portion of the Williston Basin. The MBMG study of Bakken well IPs provides information that may help identify some of the geologic factors impacting well productivity.




*Map of initial daily oil production rates of Bakken wells in eastern Montana.*

# DATA PRESERVATION AND MINING ARCHIVES

## Summary

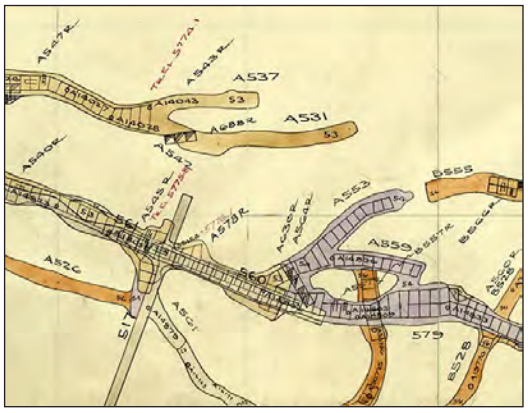
The Data Preservation Program continued to rescue and preserve historical mining and geology information, and convert it to digital media, increasing its access and use by public and private users from Montana and throughout the country.

The MBMG's Data Preservation webpage continues to expand public awareness of our preservation efforts and lead to acquisition of new collections. Development of more sophisticated digital processing and online archival information availability increased its demand from government agencies, consulting firms, private geologists, and the public. In the period between July 2018 and June 2020, our webpage was visited an average of 700 times each month, for a total of 680,000 searches that delivered 1.8 million records.

## Grants

The USGS National Geological and Geophysical Data Preservation Program (NGGDPP) grant funding (100% matching funds are required) supported the following data rescue and preservation of data efforts:

- We inventoried and digitized 50 stope books for underground mines in the Summit Valley (Butte) Montana Mining District. The books compile mining and geologic data collected from the 1880s to 1982; these books are one-of-kind and each one presents detailed maps of each layer of a particular mine (see figure at right). In cooperation with the owners, about 50 books were scanned and the images made available to the public.




*Each page of the stope book is an annotated map of the workings on a specific level of the mine. The grid spacing on the map is 2 inches.*

- We received funding to develop an archive for over 400 rock specimens and associated analytical data. The project will build a specimen archive to store current and future collections and develop a digital repository to store analytical data published in Montana. The proposed specimen archive and analytical database will enhance public access to materials stored in these collections with potential to stimulate scientific research and economic geology investigations in Montana. These repositories will also provide the framework for incorporating other inventoried collections held by the MBMG.

- The MBMG was awarded funding from the U.S. Geological Survey to evaluate mineral resources in Montana. The project includes an update of our Data Preservation inventory to support a Critical Mineral Resource map of Montana by combining multiple in-house data sets, such as water chemistry and mineral assays, along with our Critical Mineral Resource Inventory. The production of a high-quality Critical Minerals Resource map for the State will be of great interest to our stakeholders and will also serve to improve domestic understanding of Montana's mineral resources.

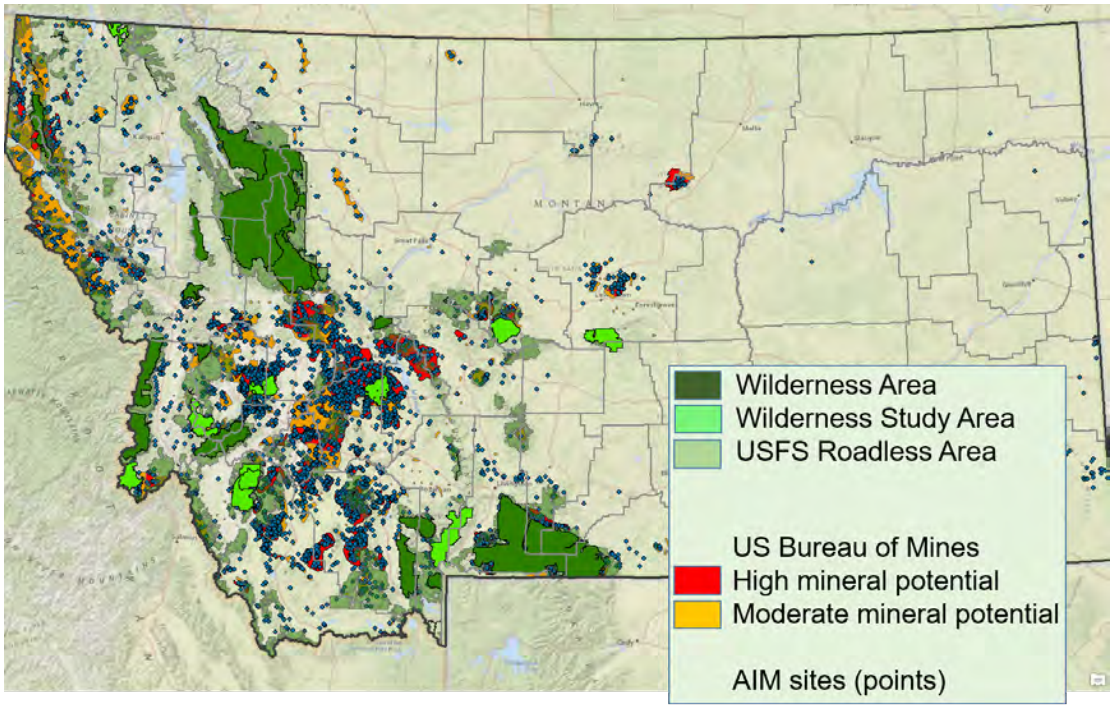
## Agency Collaboration

Staff routinely provide digital and paper copies of claims, prospects, mines, underground mine workings, oil and gas, and historic geologic data to local, State, and Federal agencies.

The program received funding through a cooperative agreement with the U.S. Forest Service to preserve geologic, hydrogeologic, and mine engineering data related to the Beal Mountain Mine. Preservation of the data will include inventory, stabilization, scanning, digital restoration, and storage of more than 130 documents, reports, and maps related to the site.

*Butte–Silver Bow (BSB) Government:* We provided transparent mining claim and feature overlays to assist the BSB Reclamation Specialist to identify possible property subsidence problems; staff provide updated files as they scan additional historic claim maps.

Mineral resource maps published by the U.S. Bureau of Mines, the U.S. Geological Survey, and the MBMG in the 1970s were produced long before geographic information systems (GIS) were available. The Montana Congressional offices made several requests for these data as they relate to the proposed Wilderness Study Areas (WSAs) in Montana. Our Data Preservation and GIS programs produced an ArcGIS project that compiled and georeferenced 67 reports and 80 maps for the 31 Bureau of Land Management WSAs, 60 maps for the 10 U.S. Forest Service WSAs, and 8,400 mine sites in the MBMG mines database for research supporting Congressional and Montana Legislation.




*Statewide compilation of mineral resources and mines in Montana Wilderness Study Areas.*

## Direct Support of Education

In addition to employment and training, the program provides the opportunity for students to integrate their work with education. The data preservation program employs 6 to 10 undergraduate students through the year. The students learn archiving methods, digital reproduction, and other computer skills that enhance their education experience at Montana Tech. The program routinely provides information to undergraduate and graduate researchers.

## Selected Recent Projects

**Lloyd C. Furer Cross Sections**

Lloyd Furer, former geologist at the Indiana Geological Survey and instructor at Indiana's famous field camp in Montana, spent decades interpreting and correlating geophysical logs from oil and gas wells across the northern Great Plains and Rocky Mountains. His work resulted in paper records of thousands of log interpretations and hundreds of cross sections that he recently donated to several state surveys, including the MBMG. This collection of cross sections comprises just a portion of Lloyd's work in Montana.

Each cross section is an interpretation of the geologic layers that occur in the subsurface between oil and gas drill holes. For each well on the cross section, geologic formations were inferred from geophysical and lithological logs. Some of the cross sections are regional, covering large portions of Montana; others are local, focused only on specific areas or oil/gas fields. These cross sections are an excellent resource for geologists actively working in Montana and for those doing geologic research in Montana – particularly those involved with subsurface geology, resource exploration, hydrogeology, water/$CO_2$ disposal, seismic hazards, and academia. This collection of geologic cross sections represents a wealth of knowledge made available to the public through this generous donation.

**Core Samples**

The MBMG has several collections of core samples and rock specimens from Montana as well as around the world that support mineralogical and geological research. This past biennium, we acquired several new core-sample collections of great interest. Some of these include:

- About 195,000 linear feet of core collected from the Belt Formation than underlies western Montana, central and northern Idaho, and southeastern British Columbia;
- several thousand feet of core from the Heddleston Mining District in the Upper Blackfoot Mining area near Lincoln, Montana;
- and a small amount of core from the the Marysville Known Geothermal Resource Area in west-central Montana.

# EASTERN MONTANA GEOLOGY AND HYDROGEOLOGY

## Billings Office


The Billings Office of the Montana Bureau of Mines and Geology was established in 1967 to inventory coal resources and investigate development-associated impacts to water resources. The Billings Office staff specializes in geologic and hydrogeologic research of Montana's energy resources and hydrogeology studies unique to the semi-arid, agricultural settings of eastern Montana.

Recent activities include work funded through the MBMG Groundwater Investigation Program, the Montana Department of Natural Resources, Montana Department of Environmental Quality, the U.S. Bureau of Land Management, the U.S. Office of Surface Mining and Reclamation, the National Science Foundation, and the U.S. Geologic Survey.

## Regional Watershed Studies

- Mapping the West Crane buried valley aquifer; Richland County
- Identifying sources of elevated salinity to the Musselshell River; Musselshell County
- Fox Hills aquifer flowing well remediation; Richland County
- Identifying and quantifying irrigation sources of groundwater recharge; Yellowstone, Big Horn and Carbon Counties
- Medicine Lake model calibration expansion; Sheridan County
- Clear Lake aquifer monitoring; Sheridan County

*Flood irrigation in Musselshell County.*

*Don Sasse joined the Billings Office in January of 2020 to assist with ongoing hydrogeology studies*

## Energy and Groundwater Studies

- Isotopic fingerprinting and tracing of acid mine drainage in the Great Falls coal field; Cascade County
- Long-term groundwater monitoring around coal mines and coalbed methane fields; Rosebud, Big Horn, and Powder River Counties
- Tracing sulfate and salt mobilization from coal spoils; Rosebud County
- Historic oil brines in the Musselshell River; Musselshell and Petroleum Counties

*Monitoring well in eastern Montana, with visitors.*

*Shawn Kuzara measuring flow rates in an irrigation canal.*

## Eastern Montana Geology

- Regional cross sections
- Digital subsurface mapping
- Digital Precambrian basement structure mapping
- Rare earth element (REE) characterization through Earth MRI
- Coal as a potential REE reservoir

## Our Partners and Collaborators

The MBMG works with Federal, State and local partners in almost every research effort to ensure we meet the research needs of eastern Montanans.

# ECONOMIC GEOLOGY

In 2014 the MBMG's Economic Geology program began to reevaluate the potential for metallic mineral deposits in historic mining districts for future exploration. Currently, the MBMG is continuing to focus on mining districts associated with the Boulder Batholith. There is renewed interest in the mining industry to explore for critical metals used in batteries, high tech electronics, renewable energy projects, and electric cars. Some of these elements include cobalt, cadmium, lithium, vanadium, germanium, gallium, tellurium, and rare earth elements. Since these elements are considered critical because 100% of these elements are imported into U.S., a new program, Earth Mapping Resource Initiative (Earth MRI), was started by the USGS in 2019. The goal of the program is to conduct a nationwide inventory identifying geologic environments favorable for critical element resources. Montana was included on the list to receive funding from the Earth MRI program. The first Earth MRI project was started in 2020 on the Elkhorn Mountain quadrangle including the Elkhorn mining district, Jefferson County. Other Earth MRI project proposals are being submitted in 2020 to the USGS for funding consideration.

Results from the lead isotope study were completed on the Boulder Batholith and published in 2019 as Bulletin 139. Results indicate a relationship between the intrusions and volcanic rocks and vein systems, suggesting a magmatic source for mineralizing fluids.

The Oro Fino mining district study was completed and published in 2020 as Bulletin 140. Analytical results for the Oro Fino district east of Galen show exploration potential for shallow epithermal silver base metal veins and a possible deep porphyry system.

Analysis was completed for the Big Foot district north of Whitehall and results were published in 2020 as Bulletin 141. Mapping and analytical results show the presence of a deep vein system that could be related to a pluton hosted by the Butte Granite of the Boulder Batholith.

*The Columbia vein is exposed in a pit adjacent to the Columbia mine and is located in the Lowland mining district, Jefferson County.*

Fieldwork was completed for the Lowland district located in the Lowland Creek drainage. Complete sample analysis is pending due to the coronavirus shutdowns.

## Current Mining Operations

Mines operated by Sibanye Gold Limited and Montana Resources are currently in production. The Golden Sunlight mine operated by Barrick Gold Corporation closed its mining operations but is still in production by reprocessing tailings.

*The Big Major mine dump in the Big Foot mining district. Tech alumni Jarred Zimmerman, a geologist with Broadway Gold Mining, pictured.*

Stillwater Mining Company was acquired by Sibanye Gold Limited, a South African gold mining company, on May 4, 2017. Sibanye Gold Limited is currently operating the Stillwater and East Boulder mines near Columbus for platinum group elements (PGE). A new decline in the Stillwater mine, the Blitz section, was completed and started production in 2017. Both mines are in production and are expected to continue into the future.

Montana Resources operates the Continental mine in Butte for copper and molybdenum. Montana Resources received approval from DEQ to expand the tailings impoundment by increasing the height of the tailings dam by 50 feet. The tailings pond expansion will accommodate another 10 years of mining. In 2018 Montana Resources began a pilot project pumping and treating water from the Berkeley Pit. They expect to recover 100,000 lbs of copper per month

from the pit water. Full-scale water treatment from the Berkeley Pit began in 2019. Operations at the Continental mine are expected to continue into the future.

Barrick Gold Corporation operates the Golden Sunlight mine near Whitehall for gold. The open pit has been closed since 2016 and underground operations closed in 2019. The mine is currently reprocessing tailings for the remaining gold as part of the reclamation plan. The tailings reprocessing operations are expected to take 10 years to complete.

## Exploration

New exploration projects for gold, silver, copper, lead, and zinc resources were started in the past 2 years, and past projects are still ongoing. Since there is renewed interest by the mining industry in critical metals, future exploration may be centered on searching for these metals.

The Black Butte copper project located near White Sulphur Springs, Meagher County, completed the exploration stage and received their final operating permit August 2020. The first development phase, constructing the surface facilities, commenced in 2020. The second phase will develop the underground mine and is expected to be completed by 2022. Sandfire Resources NL, an Australian company, took control of the project from Tintina Resources in 2017. Tintina Resources changed its name to Sandfire Resources America in 2018.

Brixton Metals Corporation started an exploration project searching for near-surface high-grade polymetallic silver–gold veins and breccia and a deep copper porphyry target in the Hog Heaven mining district located southwest of Kalispell in Flathead County. Brixton Metals drilled seven core holes in 2020. To obtain future funding for the project, Brixton Metals Corp. entered a joint venture agreement with High Power Exploration, a U.S.-based company. High Power Exploration will oversee all future exploration activities in the Hog Heaven district. Past exploration activity consisted of two geophysical surveys, construction of a new core facility, and data entry of historic assay and drill data.

Kennecott Exploration Company explored for a deep copper porphyry system in the Copper Cliff mining district located near Potomac, Missoula County. Past drilling in 2017 and 2018 located a copper porphyry deposit 4,000 feet deep with economic copper grades. Future drilling at the Copper Cliff project was placed on hold after 2018 and the exploration project was upgraded to the intermediate stage.

Kennecott Exploration Company received approval in 2019 for a drilling program located in the Beaverhead–Deerlodge National Forest 1.5 miles northwest of Maxville, MT. The exploration drilling program will take place in the vicinity of Smart Creek. The drilling program is proposed to take place over a 5-year period and entail the completion of 36 exploration drillholes searching for a potential copper resource.

*The Tuxedo mine portal is located in Deer Lodge County. MBMG Geologist Kaleb Scarberry pictured.*

The Gallatin National Forest was closed in 2018 to mineral entry, suspending Lucky Minerals' plans to continue with their exploration project in the Emigrant mining district.

Winston Gold Corporation started developing the historic Custer and Edna gold mines located 2 miles southwest of Winston, MT. Surface drilling from 2014 to 2018 showed gold ore remains in unmined portions of the Custer vein and Edna extension. A decline, the Carrabba Tunnel, was driven in 2019 along the Custer vein and the Custer mine tunnel #1 was rehabilitated. Underground drilling from the decline continues through 2020. Winston Gold Corp. reported a production in 2020 of 4,200 tones of ore with a grade of 0.22 oz/t gold. The exploration project is permitted under the Small Miners Exclusion Act.

Hecla Mining Is still undergoing the permitting process to open the Montanore and Rock Creek Mines. For the Rock Creek project, the U.S. Forest Service in 2017 issued a final Supplemental Environmental Impact Statement. For the Montanore project a court order required the U.S. Forest Service to submit a new Record of Decision and U.S. Fish and Wildlife Service to submit a new Biological Opinions report. In 2019 Montana District Court struck down the water use permit issued by the Department of Natural Resources and Conservation for the Rock Creek mine. The ruling was appealed by Hecla and the decision is still pending. In spite of the ruling, Hecla continued with their exploration activities at the Montanore and Rock Creek mines.

# 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 hosted approximately 9,800 visitors, including 42 tour groups, composed of 1,300 adults and children. The Mineral Museum also prepared cases for display at both the 2018 and 2019 Denver Mineral Shows and Butte Mineral Shows.

Over this biennium, the Mineral Museum received 120 new specimens.


*A display case featuring the Monninger Collection. Donation was September 2019 Photo credit: Catherine McKillips, MBMG.*

Significant donations include:

- 65 specimens from the Frank and Trella Monninger collection. The specimens were collected by Frank and Trella while Frank worked for the Anaconda Company in Montana, Arizona, and Chile. The collection was donated by Trella Monninger and her family.
- Dana Hartman donated 38 native copper specimens from various mines in Michigan.
- Monte Smith donated a gold nugget (85 grams) that his father (Eldon Smith) mined at Confederate Gulch in Broadwater County, Montana.
- Dr. Richard Berg donated a collection of heat-treated sapphires from Rock Creek, Philipsburg, Montana.
- A plaque displaying a ½ troy ounce gold coin was donated by The Golden Sunlight Mine.


*Eldon Smith found this 2.7-oz gold nugget in Confederate Gulch in 1965. Donated by Monte Smith.*


*MBMG Director John Metesh accepting a plaque with a gold coin from Golden Sunlight representative Rick Jordan. Donation was October 2019.*

# ANALYTICAL LABORATORY

*The Lab recently purchased a Thermo Scientific ISQ 7000 Single Quadrupole GC-MS.*

The MBMG Analytical Laboratory conducts analytical method development and sample analyses in support of research being done by MBMG programs. Although the lab is licensed by the State of Montana–Department of Health and Human Services to analyze drinking water supplies, we typically do not perform analyses for the general public. Our QA/QC program meets criteria established by the U.S. Environmental Protection Agency and the U.S. Geological Survey.

The inorganic lab routinely determines major anions, cations, trace metals, selected rare earth metals, selected isotopes, alkalinity, pH, and radon. The primary focus of the organic lab is the determination of acidic compounds, polynuclear aromatic compounds, and extractable petroleum hydrocarbons in waters and soils. All groundwater data obtained by the lab are reported in the GWIC database. In addition to supporting the numerous research projects and ongoing monitoring by MBMG programs, the Analytical Lab works closely with Montana Tech and other universities within the Montana University System (MUS) to provide analyses to both graduate and undergraduate research. Available instrumentation includes:

- Thermo Scientific iCAP Q inductively coupled plasma/mass spectrometer (ICP/MS) for trace metal analyses
- Thermo Scientific iCAP 6000 Series inductively coupled plasma optical emission spectrometer (ICPOES) for determining major cations
- Thermo Scientific ISQ 7000 VPI gas chromatograph with mass spectrometer detector (GC/MS) for organic compounds and extractable hydrocarbons
- Two Metrohm Compact IC Plus instruments for anion analyses
- Metrohm Robotic Titrator for measuring pH, conductivity, and alkalinity
- Picarro Isotopic Water Analyzer, L2130-i for water isotope analysis
- Picarro δ13C High-Precision Isotopic carbon dioxide ($CO_2$) analyzer, G2131-i for $^{13}C$ isotopic analysis of $CO_2$ in water; a Costech Combustion Module was added to the Picarro G1231-i to allow for $^{13}C$ isotopic analyses of solid samples
- Aurora 1030 Wet Oxidation TOC Analyzer for analyzing organic and inorganic carbon in water samples
- Agilent gas chromatograph with mass spectrometer detector (GC/MS) for organic compounds
- Hidex 300SL Liquid Scintillation Counter for determination of radon in water

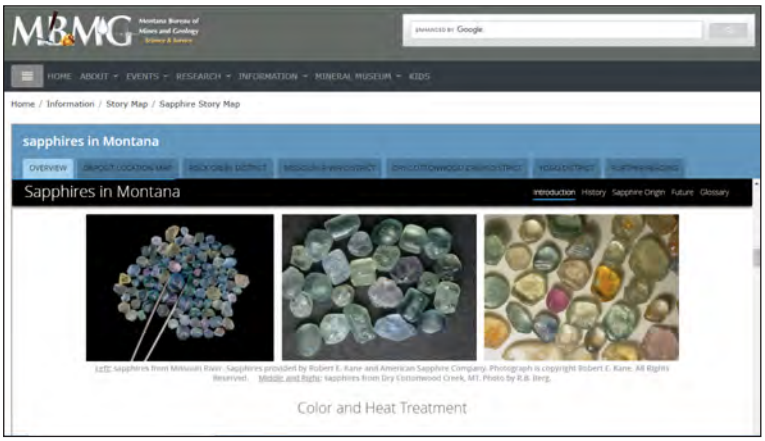
# GIS LABORATORY

The Geographic Information Systems (GIS) Lab continues to provide support for a number of different programs within the MBMG. Geologic mapping has long been a primary component of the activities within the GIS Lab, and continues to be the largest ongoing project for GIS staff.

The MBMG, in coordination with the U.S. Geological Survey (USGS), has adopted a newer database design, the successor to the National Geologic Mapping Program 2009 data model (NCGMP09). The Geologic Mapping Schema (GeMS) design is a leap forward for characterizing geologic map data. The MBMG has adopted the design and will release all future GIS datasets in this format. The GeMS format uses the Environmental Systems Research Institute (ESRI) file geodatabase for the spatial database standard to carry the data encompassing a geologic map.

Online mapping is an ongoing effort within the MBMG. Several StoryMaps have been released over the past few years. StoryMaps provide rich content with a combination of maps, diagrams, and data to explain information that engages viewers. MBMG StoryMaps can be found at this URL: https://www.mbmg.mtech.edu/information/storymaps/storymap.asp.

Web mapping applications are another up and coming effort on the part of the MBMG GIS Lab. A web mapping application can deliver different types of mapping information that is linked to a database(s) behind the scenes. The MBMG's geologic maps are now available through a web mapping application: https://www.mbmg.mtech.edu/information/geologicmap.asp. The MBMG will continue to develop more web mapping applications and offer online map services for many years to come.



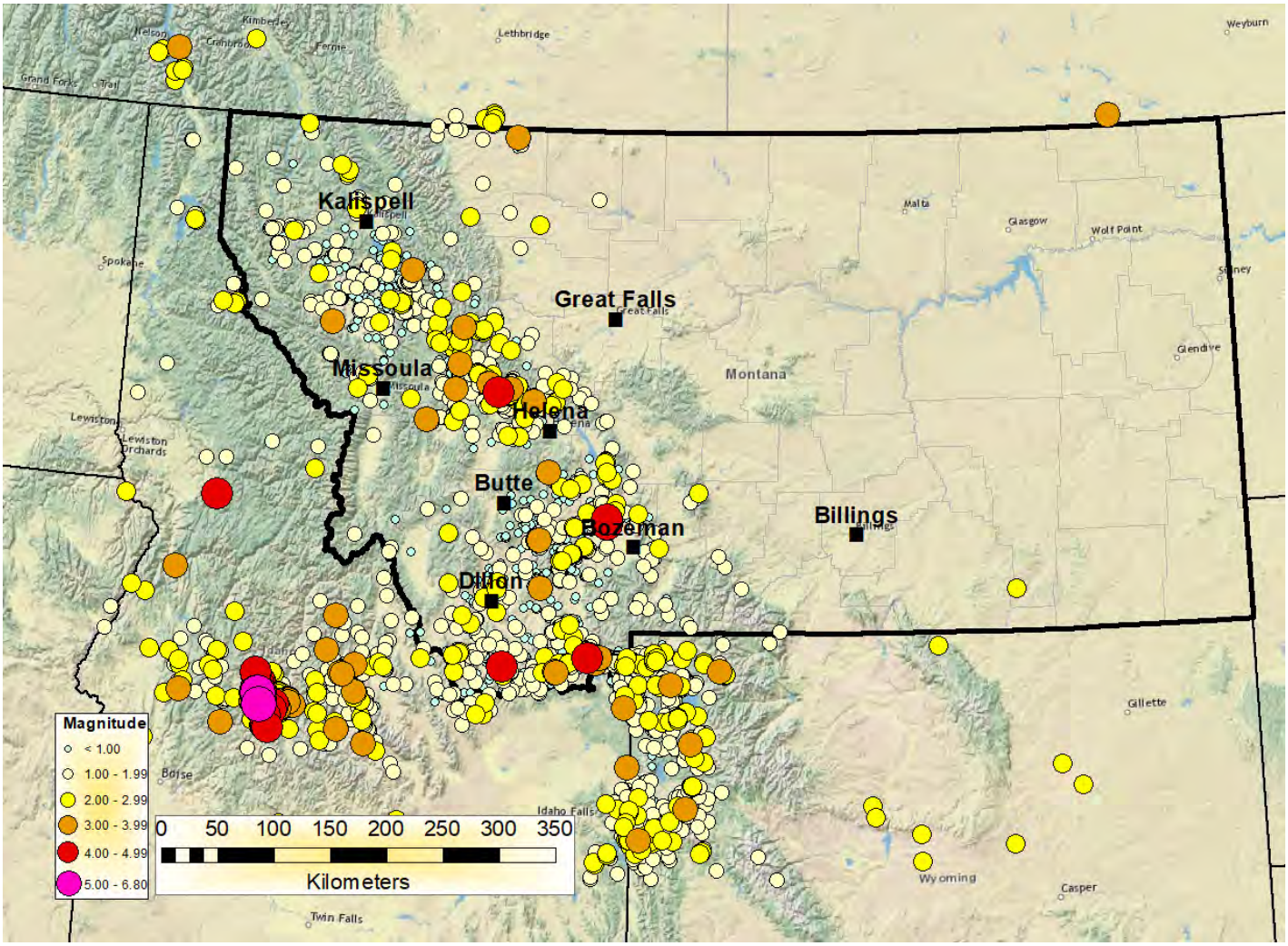

Staff in the GIS Lab respond to numerous requests for support from within and outside the MBMG. Staff provide support to data end users for geologic map data, GWIC well data, and online mapping services (from MBMG & ESRI).

# EARTHQUAKE STUDIES

Western Montana has a history of large, damaging earthquakes and remains seismically active. Most 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 fault mapping 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 41 seismic monitoring stations throughout western Montana, the most seismically active region of the State. The MBMG receives seismic data from eight USGS stations in Montana, including four stations in eastern Montana. Other regional seismic monitoring centers in Utah, Idaho, Washington, and Canada exchange seismic data with the MBMG and provide additional monitoring coverage near Montana's borders. The MBMG has installed NetQuakes seismographs at five homes and fire stations in western Montana, which detect significant ground motions at urban locations and send the data to a central server via the internet. The MBMG also began recording seismic data from three amateur-operated seismograph stations in western Montana.

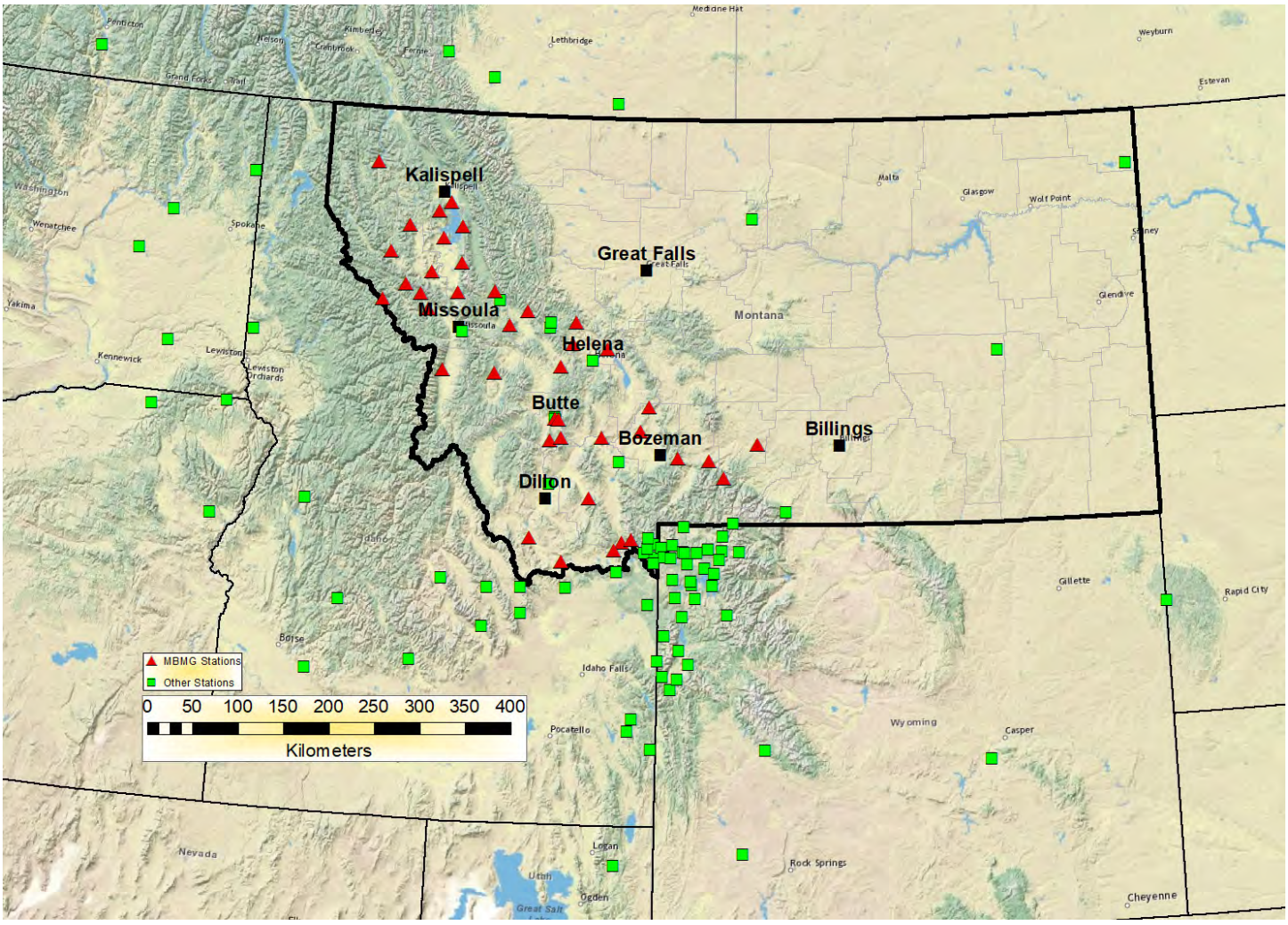
The MBMG records a total of 286 channels of real-time seismic data from 114 local and regional stations in 17 different networks. These seismic data are used to detect and report earthquake locations and magnitudes to the National Earthquake Information Center. State and Federal agencies (Montana Disaster 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 7,448 earthquakes and 2,525 open-pit mining blasts with magnitudes ranging from -1.2 to 6.5 from July 1, 2018 to June 30, 2020.




*Epicenter locations for 7,448 earthquakes located by the MBMG from July 1, 2016 to June 30, 2018.*

The largest earthquake in Montana during this period occurred on April 9, 2019 and was centered 6 miles northeast of Lima. Citizens reported feeling this magnitude 4.9 earthquake from Great Falls to Idaho Falls and from Bozeman to Missoula. A magnitude 4.2 earthquake on February 29, 2020 occurred in the southern Madison Valley and was reported felt by 27 residents as far north as Helena and northwest to Missoula. A magnitude 4.3 earthquake southeast of Lincoln on February 3, 2019 was reported felt by 53 residents throughout west-central Montana. This earthquake, along with 906 smaller events, represent late aftershocks of the magnitude 5.8 Lincoln earthquake of July, 6, 2017. An earthquake swarm centered just west of Manhattan from September 29, 2018 to June 14, 2020 included 899 earthquakes. The largest Manhattan swarm earthquake occurred on August 16, 2019 with a magnitude of 4.7 and was reported felt by 447 residents in western Montana. The Manhattan swarm included 19 earthquakes of magnitude 3.0 or larger, and 51 earthquakes residents reported feeling. The Manhattan earthquake swarm occurred along a buried northwest-trending fault that was previously unrecognized.

Current seismograms from the MBMG network are available on the MBMG Earthquake Studies Office website (http://www.mbmg.mtech.edu/quakes/quake.asp), 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 2018–2020 earthquakes. Seismograph stations operated by the MBMG are shown in red; stations operated by other agencies including the U.S. Geological Survey, University of Utah, Idaho National Labs, University of Washington, University of Idaho, Canadian Geological Survey, and Alberta Geological Survey, are shown in green.*

# 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

B 138, Butte, Montana: The Berkeley Pit, changes in water quality and water sampling methods, 1982–2017, Duaime, T.E., and McGrath, S.F., 2019

B 139, Interpretations of new and previous lead isotopic data for Late Cretaceous to Eocene satellite intrusions, Butte granite, volcanic rocks, and base metal veins of the Boulder Batholith, southwestern Montana, Korzeb, Stanley L., 2019

B 140, Genesis and exploration potential for Eocene age veins of the Oro Fino mining district, Deer Lodge County, Montana, Korzeb, S.L., and Scarberry, K.C., 2020

### Digital Publications

DIGITALPUB 2, Montana's seismic hazards, Li, Y., and Stickney, M., 2019

### EDMAP

EDMAP 13, Geologic map of the northern half of the Pintler Lake 7.5' quadrangle and the southern half of the Warren Peak 7.5' quadrangle, southwestern Montana, Howlett, C.J., Reynolds, A.N., and Laskowski, A.K., 2020

### Geologic Maps

GM 71, Geologic map of the Bison Mountain 7.5' quadrangle, Powell and Jefferson counties, Montana, Scarberry, K.C., Coppage, E.L., and English, A.R., 2018

GM 72, Geologic map of the Ramsay 7.5' quadrangle, southwestern Montana, Scarberry, Kaleb C., 2019

GM 73, Geologic map of the Twin Adams Mountain 7.5' quadrangle, southwestern Montana, McDonald, C., and Yakovlev, P., 2019

GM 74, Geologic map of the Glen 7.5' quadrangle, southwestern Montana, Yakovlev, P., 2019

GM 75, Geologic map of the Montana part of the Salmon 30' x 60' quadrangle, southwestern Montana, Lonn,J.D., Elliott, C.G., Lewis, R.S., Burmester, R.F., McFaddan, M.D., Stanford, L.R., and Jänecke, S.U., 2019

GM 76, Geologic map of the Bannock Pass 7.5' quadrangle, Beaverhead County, Montana, and Lemhi County, Idaho, Lonn, J.D., Elliott, C.G., Stewart, D.E., Mosolf, J.G., Burmester, R.F., Lewis, R.S., and Pearson, D.M., 2019

GM 77, Geologic map of the Elliston 30' x 60' quadrangle, west-central Montana, McDonald, C., Mosolf, J.G., Vuke, S.M., and Lonn, J.D., 2020

GM 78, Geologic map of the south half of the Shaw Mountain 7.5' quadrangle, southwestern Montana, Lonn, Jeffrey D., 2020

### Ground-Water Atlas Series

GWAA 6-02, Hydrogeologic map of Carbon and Stillwater Counties, south-central Montana, Blythe, D.D., and LaFave, J.I., 2020

### Memoirs

M 69, Estuarine deposits in the Kootenai Formation as evidence of an early Cretaceous (pre-Albian) marine advance into western Montana and relationship to Cordilleran foreland basin evolution, Schwartz, R.K., and Vuke, S.M., 2019

### Open-File Reports

MBMG 705, History and hydrogeology of the Berkeley Pit, Butte, Montana, 1955–2017, Duaime, T.E., and Smith, S.M., 2018

MBMG 706, Flat Creek groundwater source investigation report, Icopini, G., 2018

MBMG 707, 2017 Annual coalbed-methane regional groundwater monitoring report: Powder River Basin, Montana, Meredith, E., Bierbach, S., Wheaton, J., Kuzara, S., and Blais, N., 2018

MBMG 708A–G, Lewistown structure contour line maps, Bergantino, R.N., 2019–2020

MBMG 709, Butte Mine Flooding Operable Unit water-level monitoring and water-quality sampling 2017 consent decree update, Butte, Montana, 1982-2017, Duaime, T.E., McGrath, S.F., Icopini, G.A., and Thale, P.R., 2019

MBMG 710A–E, Cut Bank structure contour line maps, Bergantino, R.N., 2019–2020

### Information Services Statistics

**Publication Sales:**

- 936 titles
- 9,763 items sold
- 90 items published/released

**Data downloaded:**

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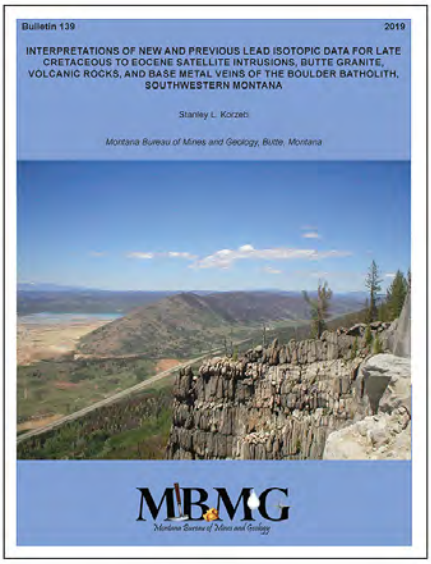



MBMG 711A–H, Roundup structure contour line maps, Bergantino, R.N., 2019–2020

MBMG 712, Initial (60–90 day) average daily production rates for horizontal wells completed in the Bakken and Three Forks Formations, eastern Montana, Gunderson, J.A., and Wunder, J.M., 2019

MBMG 713, Stratigraphic cross section of Mississippian through Lower Cretaceous rocks across central Montana from the fold-thrust belt to the Williston Basin, Gunderson, J.A., and Furer, L.C., 2019

MBMG 714A–E, Shelby structure contour line maps, Bergantino, R.N., 2019–2020

MBMG 715, Geology of the Butte North 30' x 60' quadrangle, southwest Montana, Scarberry, K.C., Elliott, C.G., and Yakovlev, P.V., 2019

MBMG 716, West Billings groundwater model: Aquifer response to land-use change in the West Billings area, Montana, Chandler, K., and Reiten, J., 2019

MBMG 717A–H, Hardin structure contour line maps, Bergantino, R.N., 2019–2020

MBMG 718A–G, Havre structure contour line maps, Bergantino, R.N., 2019–2020

MBMG 719, 2018 Annual coalbed-methane regional groundwater monitoring report: Powder River Basin, Montana, Meredith, E., Wheaton, J., Kuzara, S., and Bierbach, S., 2019

MBMG 720, South Medicine Lake area of the Clear Lake aquifer: Groundwater Model report, Chandler, K., and Reiten, J., 2019

MBMG 721, Where has the water gone?: Destinations where water samples from the Berkeley Pit and Horseshoe Bend have been sent for treatability studies and research purposes, Duaime, T.E., Thale, P.R., and Thomson, C.J., 2019

MBMG 722A–G, Ekalaka structure contour line maps, Bergantino, R.N., 2019

MBMG 723A–H, Billings structure contour line maps, Bergantino, R.N., 2019

MBMG 724A–C, Choteau structure contour line maps, Bergantino, R.N., 2020

MBMG 725A–B, Great Falls structure contour line maps, Bergantino, R.N., 2020

MBMG 726, Virginia City Aquifer Test, Bobst, Andrew L., 2020

MBMG 727, Aquifer tests in the Upper Jefferson Valley, Bobst, A.L., and Gebril, A., 2020

MBMG 728, Geologic map of the Cadotte Creek 7.5' quadrangle, west-central Montana, Bregman, Martin, 2020

MBMG 729, MBMG Analytical Laboratory: Quality Assurance Manual, Timmer, Jacqueline, 2020

MBMG 730, Richland County Fox Hills aquifer well inventory: Assessing conditions of flowing artesian wells, Chandler, K., Reiten, J., and Wolfram, M., 2020

MBMG 731, Butte Mine Flooding Operable Unit water-level monitoring and water-quality sampling 2018 consent decree update, Butte, Montana, 1982–2018, Duaime, T.E., McGrath, S.F., Icopini, G.A., and Thale, P.R., 2020

## Miscellaneous Publications

MISC 65, 2019 MBMG Calendar: 100 Years of Science and Service for Montana, Metesh, J.J. and Barth, S., 2018

MISC 67, 2020 MBMG Calendar: Trapper Peak, Bitterroot Mountains, Lonn, J.D., 2019

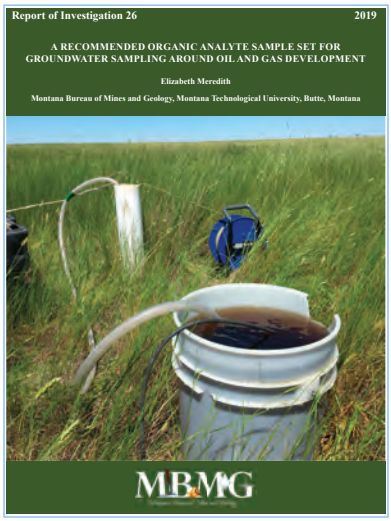
## Reports of Investigation

RI 26, A recommended organic analyte sample set for groundwater sampling around oil and gas development, Meredith, E., 2019

## Special Publications

SP 120, Proceedings of the Montana Mining and Mineral Symposium 2018, Scarberry, K.C., and Barth, S., editors, 2019

SP 121, Proceedings of the Montana Mining and Mineral Symposium 2019, Scarberry, K.C., and Barth, S., editors, 2020



# MBMG GRANTS AND CONTRACTS

## in effect during this biennium

Abdo, G., Water Efficiency & Management, Farmers Canal Company of Gallatin County
Bobst, A., Shallow Aquifer Study, MT Department of Natural Resources and Conservation
Bobst, A., Hydrologic Monitoring & Analysis, Nature Conservancy
Buckley, L., Montana University System Wellness Grant
Chandler, K., Medicine Lake Groundwater Model, MT Department of Natural Resources and Conservation
Chandler, K., Richland County, Richland County Conservation District
Chandler, K., Clear Lake Aquifer, Sheridan County Conservation District
Crowley, J., Proximity Alert System for COVID-19, Edward Meier
Crowley, J., Season Spatial Distribution/Water Center, Montana University System, U.S. Geological Survey
Delaney, M., Data Preservation, U.S. Department of Interior–Geological Survey
Duaime, T., Natural Resources Damage Program, MT Department of Justice
Duaime, T., Selection of Well Samples, Butte Silver Bow
Duaime, T., Mouat Industries Groundwater Monitoring, MT Department of Environmental Quality
Duaime, T., Butte Mine Flooding, MT Department of Environmental Quality
Duaime, T., Bullion & Crystal Mine, MT Department of Environmental Quality
Duaime, T., Beal Mountain Mine, U.S. Department of Agriculture–Forest Service
Duaime, T., MRI–Berkeley Pit Remote Sampling, MT Recourses Inc.
Duaime, T., Groundwater Assessment, U.S. Department of Agriculture–Forest Service
Duaime, T., Stream Flow Monitoring, Montana Resources
Duaime, T., Granite Mountain Mine Well Replacement, Montana Resources
English, A., Yellowstone Controlled Ground Water Area, U.S. Department of Interior–National Parks Service
Hargrave, P., and Scarberry, K., Stope Book Rescue, U.S. Geological Survey
Icopini, G., Rocker Controlled Groundwater, MT Department of Environmental Quality
Icopini, G., Belt Technical Assist., MT Department of Environmental Quality
Icopini, G., Mouat Industries Groundwater Monitoring, MT Department of Environmental Quality
Icopini, G., Glacier and Toole Groundwater Survey, MT Department of Natural Resources and Conservation
Kuzara, S., Acid Mine Discharge, MT Department of Environmental Quality
Kuzara, S., Carbon County CD/ Pivot-installation, Carbon County Conservation District
Kuzara, S., Isotopic Fingerprint, U.S. Department of Interior–Office of Surface Mining
Kuzara, S., Groundwater Recharge, Big Horn Conservation District
Kuzara, S., Measuring Groundwater Recharge, Department of Natural Resources and Conservation
LaFave, J., DNRC Baseline GWIC Data Entry, MT Department of Natural Resources and Conservation
LaFave, J., MT NGWMN, U.S. Department of Interior–Geological Survey
LaFave, J., National Groundwater Monitoring, U.S. Department of Interior–Geological Survey
LaFave, J., NRCS Technical Assistance, U.S. Department of Agriculture–Natural Resource Conservation Service
LaFave, J., NRCS Technical Data, U.S. Department of Agriculture–Natural Resource Conservation Service
McDonald, C., StateMap, U.S. Department of Interior–Geological Survey
Meredith, E., Groundwater Monitoring, U.S. Department of Interior–Bureau of Land Management
Meredith, E., Water Quality Eastern MT, MT Department of Natural Resources and Conservation
Meredith, E., Oil/ Gas Eastern MT, MT Department of Environmental Quality
Meredith, E., Custer National Forest, U.S. Department of Agriculture–Forest Service
Meredith, E., Characterizing Naturally Occurring Contamination, MT Department of Natural Resources and Conservation
Metesh, J., Yellowstone National Park Database Administration, National Park Service
Metesh, J., Montana's Seismic Hazards, MT Disaster and Emergency Services
Metesh, J., Earthquake Hazards Reduction, MT Disaster and Emergency Services

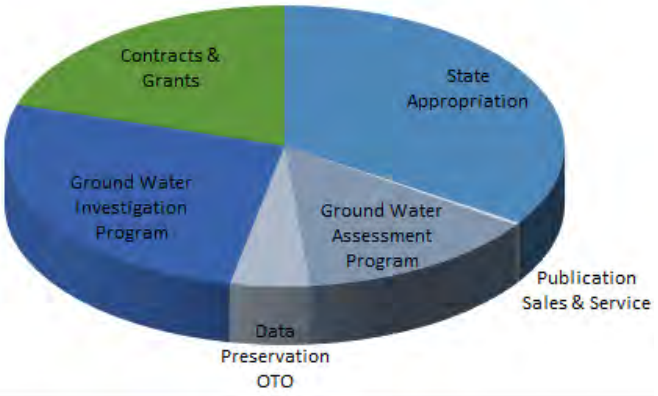
# FINANCES

The Montana Bureau of Mines and Geology was established in 1919 to collect, interpret, and publish information on 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. The MBMG comprises about 31 research professionals, 24 technical/clerical positions, and 5 to 10 students.

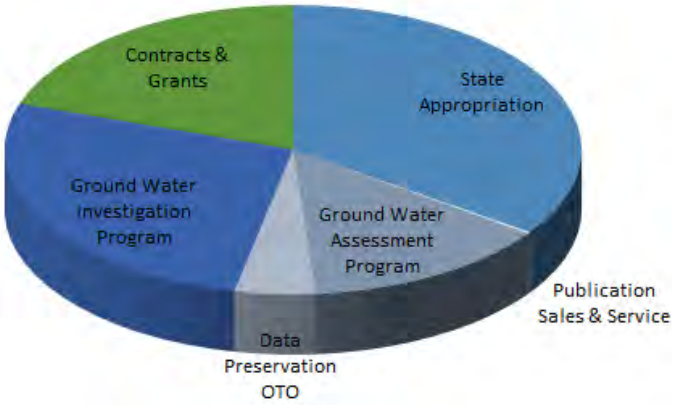
Funding for the past biennium came from seven categories: (1) a biennial appropriation from the State's general fund to maintain core programs; (2) a biennial appropriation from the State's general fund for the Ground Water Investigation Program; (3) a statutory appropriation for the Ground Water Investigation Program provided by the 2019 Legislature; (4) biennial appropriations from the State's special accounts for the Ground Water Assessment Program; (5) contracts and grants derived through agreements with a variety of Federal, State, and local organizations to address specific issues of mutual interest to the sponsoring organization and the MBMG; (6) income from sales of MBMG publications; and (7) a special one-time-only appropriation for Data Preservation provided by the 2019 Legislature.

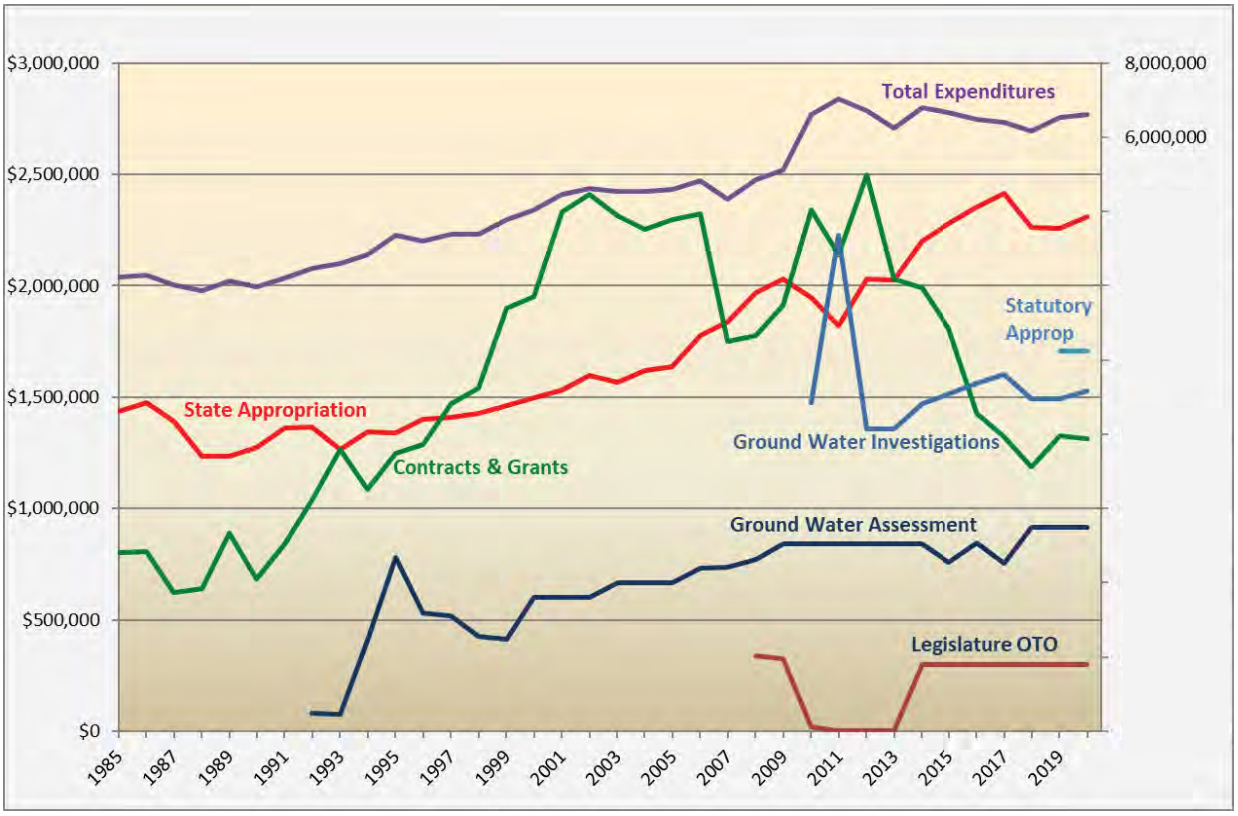
The long-term trend for the four major sources of funding continues upward at a modest rate; the generosity of the Montana Legislature and Governor is reflected in the steady growth of the core geologic programs as well as the recent addition of the new ground water program. Many of the projects under contracts and grants rely on partial state support (matching funds); the decline in "soft money" reflects continued reduction of funds from Federal sources as well as declining activities related to Superfund.

**FY 2019**




**FY 2020**



# MBMG STAFF

## Director's Office

**John J. Metesh,** Professor, Director and State Geologist
**Shelley Reed,** Administrative Associate III

## Accounting

**Sara Lester,** Budget Analyst II

## Analytical

**Jacqueline Timmer,** Associate Professor, Chief Chemist
**Ashley Huft,** Chemist

## Computer Services and Geographic Information Systems

**Jeff Johnson,** Computer Support Specialist III
**Yiwen Li,** Professional Scientist, GIS Specialist
**Paul Thale,** Assistant Professor, GIS Manager

## Information Services

**Susan Barth,** Assistant Professor, Chief Information Services Division, Publications Editor
**Susan Smith,** Geologic Cartographer

## Research Staff

**Madeline Gotkowitz,** Chief Research Division

**Ginette Abdo,** Professor, Ground Water Investigation Program Manager
**Richard Berg,** Professor Emeritus, Geologist
**Robert Bergantino,** Professor Emeritus, Geologist
**Jim Berglund,** Assistant Professor, Hydrogeologist
**Andrew Bobst,** Professor, Hydrogeologist
**Ron Breitmeyer,** Associate Professor, Hydrogeologist
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**Camela A. Carstarphen,** Associate Professor, Hydrogeologist
**Jeremy Crowley,** Assistant Professor, Hydrogeologist
**Terence E. Duaime,** Assistant Professor, Hydrogeologist
**Colleen Elliot,** Professor, Geologist
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**Yann Gavillot**, Assistant Professor, Geologist
**Ali Gebril,** Associate Professor, Hydrogeologist
**Denise Herman**, Research Assistant III
**Gary Icopini,** Professor, Hydrogeologist
**Stacey Konda,** GWIC Lab Manager
**Stanley Korzeb**, Professor, Geologist
**John I. LaFave,** Professor, Ground Water Assessment Program Manager
**Jeffrey D. Lonn,** Professor, Geologist
**James Madison,** Associate Professor, Hydrogeologist
**Bulbul Majumder**, Software Engineer
**Donald C. Mason,** Research Assistant III
**Catherine McDonald,** Professor, Geology Program Manager
**Steve McGrath,** Analytical Chemist
**Jesse Mosolf,** Associate Professor, Geologist
**Todd Myse,** Associate Professor, Hydrogeologist
**Chelsea Pincock,** Library Technician III
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**Kaleb Scarberry,** Associate Professor, Geologist
**Dean Snyder,** Assistant Professor, Hydrogeologist
**Michael C. Stickney,** Professor, Director Earthquake Studies Office
**Mary Sutherland,** Assistant Professor, Hydrogeologist
**Connie Thomson,** Hydrogeologist
**Susan M. Vuke,** Professor Emeritus, Geologist
**Mark Wolfram,** Professional Scientist, Hydrogeologist

## Billings Office

**Simon Bierbach,** Computer Support Specialist II
**Kevin Chandler,** Assistant Professor, Hydrogeologist
**Jay Gunderson,** Professor, Geologist
**Shawn Kuzara,** Associate Professor, Hydrogeologist
**Elizabeth Meredith,** Professor, Hydrogeologist
**Jon C. Reiten,** Professor, Hydrogeologist

## Retirees

**Peggy Delaney**
**Nancy Favero**
**Phyllis Hargrave**
**Kirk Waren**
**John Wheaton**

# 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. Attila Folnagy , Department of Natural Resources
Mr. Chris Boe, Department of Environmental Quality
Mr. Brett Heitshusen, Department of Agriculture
Mr. Troy Blandford, Montana State Library, Natural Resources Information System

EX OFFICIO MEMBERS

**Governor Appointees**

Mr. Walt Sales, Association of Gallatin Agricultural Irrigators, Bozeman—Agricultural water users
Mr. Mark Thompson, Montana Resources Inc., Butte—Industrial water users
Ms. Jane Holzer, MT Salinity Control Assn., Conrad—Conservation or ecological protection organization
Mr. Scott Cooney, Developer, Missoula—Development community

OTHER

Dr. Payton Gardner, Montana University System, appointed by the Board of Regents
Dr. Madeline Gotkowitz, Montana Bureau of Mines and Geology
Mr. Joe Kolman, Legislative Services Division
Mr. James Halvorson, Board of Oil and Gas Conservation
Mr. Alden Shallcross, Bureau of Land Management
Mr. John Kilpatrick, U.S. Geological Survey
Mr. Jeff Baumberger, U.S. Bureau of Reclamation
Mr. Thor Burbach, USDA Forest Service
Mr. Jason Gildea, U.S. Environmental Protection Agency
Ms. Karin Hilding, City of Whitefish, appointee for Montana cities and towns

### State Map Advisory Committee

Mr. Bryan Allison, MT Dept. of Natural Resources and Conservation
Mr. Tim Bartos, U.S. Geological Survey
Dr. John Childs, Childs Geoscience
Mr. Steven J. Czehura, Applied Geological Services
Dr. Chris Gammons, Montana Technological University
Mr. James W. Halvorson, MT Board of Oil and Gas Conservation
Mr. Scott Helm, Montana Dept. of Transportation
Dr. Marc Hendrix, The University of Montana
Mr. Mike Huffine, U.S. Forest Service
Dr. David Lageson, Montana State University
Mr. Seth Makepeace, Confederated Salish and Kootenai Tribes
Ms. Kari Scannella, USDA MT Natural Resources Conservation Service
Mr. Dan Seifert, U.S. Forest Service
Mr. Garrett Smith, Montana Dept. of Environmental Quality
Mr. David Williams, Bureau of Land Management
Mr. Robert Wintergerst, U.S. Forest Service

### Yellowstone Controlled Ground Water Area Technical Oversight Committee

Dr. Steve Custer (chair), Montana State University (retired)
Mr. John Kilpatrick, U.S. Geological Survey
Mr. Attila Folnagy, 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. 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 members have served:

Anaconda RWWS Operable Unit: Groundwater Technical Review Committee
Association of American State Geologists Executive Committee
State Water Plan Basin Advisory Committees
Board of Environmental Review
Butte Mine Flooding Public Education (Pit Watch)
Butte Silver Bow Pre-Disaster Mitigation Plan Committee
Butte-Silver Bow Superfund Advisory and Redevelopment Trust Authority
Clark Fork Watershed Education Program
Coalbed Methane Protection Program
DNRC Technical Advisory Council on Coalbed Methane
Future Fisheries
Governor's Drought and Water Supply Advisory Committee's Monitoring Sub-committee
Montana Board of Water Well Contractors
Montana Geologic Society
Montana Mining Association
Montana Resources - Groundwater Modeling Working Group
Montana Section of the American Water Resources Association
Montana Water Center
National Geologic and Geophysical Data Preservation Committee
National Ground Water Monitoring Network
Science Mine
Sheridan County Water Reservation Technical Advisory Committee
Subcommittee on Groundwater to the Advisory Committee on Water Information (DOI)
Tobacco Root Geological Society
Watershed Coordination Council
Western States Seismic Policy Council
Williston Area Aquifer Models Consortium
Yellowstone TOC
Yellowstone Volcano Observatory Seismic Monitoring Team

*Photo by Colleen Elliott, MBMG.*

MBMG
Montana Bureau of Mines and Geology

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