

Biennial Report of Activities and Programs July 1, 2020 to June 30, 2022



Cover photo: Jeff Lonn, MBMG. Back photo: Susan Barth, 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; during this biennium we released several new maps, including collaborative maps with the Idaho Geologic Survey. The demand for critical mineral commodities (commonly referred to as critical minerals) has increased dramatically over the past few years; likewise, demand for information related to those resources in Montana.

The Earth Mineral Resource Initiative (Earth MRI), hosted by the U.S. Geological Survey, 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, 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 2020-2022 biennium we published 40 maps and reports; we also released two more digital "story maps." As we migrate away from paper, our online (free) downloads rapidly increase—this past biennium we provided more than 3,500 digital maps and reports.



A "Raspberry Shake" home seismograph. The MBMG was able to purchase and deploy several of these in homes where additional seismic monitoring is needed.



An MBMG hydrogeologist in the field, part of the Ground Water Investigation Program.

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 2021 Uuno Sahinen Award was presented to John Childs.



2021 Sahinen Award recipient John Childs.

John Childs was born in Syracuse, New York in 1944. He earned a BSc degree in geology from Syracuse University in 1966. He completed his education with a MSc from the University of British Columbia in 1969 and a PhD from the University of California at Santa Cruz in 1982. Fieldwork as part of university training included mapping in Maine, the Azores, British Columbia, Alaska, and Idaho. While in school, he worked for both the Canadian Geological Survey and the U.S. Geological Survey. He married Mary Ann Kopp in 1968 and they have two grown children, Colleen in Albuquerque, New Mexico and Laurie in Arlee, Montana. Both girls grew up packing rocks in the mountains for Dad.

John is a member of the Society for Mining, Metallurgy, and Exploration, the Society of Economic Geologists, the Association of Applied Geochemists, the Geological Society of America, and the Geological Association of Canada. He has served as an Adjunct Faculty Member at California State University at Los Angeles and at Montana State University. He serves on the Advisory Board for the

Earth Sciences Department at MSU. John is a Registered Geologist in California, Arizona, and Idaho and is a Founding Registered Member of the Society for Mining, Metallurgy, and Exploration. John has published on a wide variety of topics, including structural geology, talc, gold, porphyry deposits, palladium–platinum, gemstones, Arizona geology, various field trip guides, and working relationships with small miners in Brazil.

Childs has worked for several companies including Cyprus Mines Corporation, where he worked on one of the first contracts awarded in 1972 by NASA to evaluate applications of the new ERTS (LANDSAT) imagery, Pegasus Gold, and Sibayne–Stillwater. However, most of his career has been spent as an independent consultant through Childs Geoscience Inc. and its predecessor companies. Clients have included Golden Sunlight Mine during transition of ownership from Placer Dome to Barrick Gold, Aur Resources Inc., Sandfire Resources USA, Barretts Talc, Luzenac Talc, Barton International, Yogo Mining Company, Great Basin Gold, and numerous other companies and prospectors. John was a Vice President of Lupine Minerals Corporation, and a principal in the Minerals Discovery Group, the Gold Discovery Group, Lodestone Resources, and the Willow Creek Discovery Group.

John serves as a member and former Chairman of the Montana State Mapping Advisory Committee for the Montana Bureau of Mines and Geology, and as a past Vice President and current board member for the Tobacco Root Geological Society, where he is proud to have helped establish a scholarship program that has supported graduate students conducting fieldwork in the northern Rocky Mountains for the past 35 years. In 2011 Childs was presented with the Hammer Award by the Tobacco Root Geological Society for contributions to the geology of the Northern Rocky Mountains.

Childs is also honored to have led teams responsible for the discovery of new resources that are needed by society, including talc, garnet, limestone, magnesite, gold, molybdenum, copper, base metals, and gemstones. He takes great satisfaction in having hired, mentored, and helped launch the careers of over 70 young scientists, most of whom graduated from Montana universities. He also looks back fondly on the diverse exploration teams he has assembled and come to love in the U.S., Guyana, Brazil, Mexico, Canada, New Zealand, Turkey, Romania, and other parts of the world. His greatest professional joys have always been fieldwork, the thrill of discovery, and the people he meets along the way.

Retirement has not been a good fit, so John is back in the field doing what he loves: mapping and generating exploration ideas.

The 2022 Uuno Sahinen Award was presented to Donald Hyndman.

Originally from Vancouver, British Columbia (BC), Dr. Donald Hyndman spent seven undergrad and grad college summers, 1955 to 1963, mapping regional geology in the mountains of B.C. for the Geological Survey of Canada. In the summer of 1957, he worked for a Cominco and Noranda mining joint venture in the Okanagan Valley, at what became the large Brenda Cu-Mo mine. In the summer of 1958, he did exploration work for Yukon Consolidated Gold Corp. He earned his B.A.Sc. (Geological Engineering) from the University of British Columbia, Vancouver in 1959. The Canadian Geological Survey funded his doctoral research at Berkeley and he earned his Ph.D. from UC Berkeley in 1964. The CGS was clearly grooming him for a permanent position, but a country-wide hiring freeze prevented that. Plan B was college teaching, leading in 1964 to his lifelong move to Missoula, where he could continue both geology research and teaching. It was a wonderful choice. Don was recognized as a Distinguished Scholar in 1985 and as a Distinguished Teacher in 1990;

Don's teaching at UM included courses in mineralogy, igneous and metamorphic petrology, crystallography, regional tectonics, introductory geology, and roadside geology, and in later years, natural hazards. He mentored numerous grad students, many of whom went to work in mineral exploration, especially in Montana and Colorado. His research, and that of many of his students, included studies of the Idaho batholith, the mylonite zone marking the eastern flank of the batholith in the Bitterroots, origin of



batholith magmas, alkaline igneous rocks in central Montana, origin of radial dikes and laccoliths in Montana, regional tectonics of the Pacific Northwest, and sundry other aspects of Montana geology. He spent a couple of years as chairman of the University of Montana Geology department, and a sabbatical-leave year as visiting Professor at Stanford University, teaching their required undergrad course in igneous petrology, while writing the second edition of his petrology textbook. Don published two textbooks: Petrology of Igneous and Metamorphic Rocks (2 editions) and Natural Hazards and Disasters, (5 editions and working on the 6th), coauthored with David Hyndman. Don is the co-originator of the Roadside Geology Series with David Alt and coauthor with David Alt on seven Roadside Geology books: Rocks, Ice, and Water, RG Northern Rockies, Montana (1st ed.), RG Idaho, RG Washington, RG Oregon, RG Northern California, RG Northern and Central California, and two with other authors: RG Hawaii (with Richard Haslett), and Roadside Geology of Montana 2nd ed., with Robert Thomas. He also published more than 100 scientific research papers, most as sole author, as well as several other geological research volumes and geological field guides, some as sole author, others as coauthor with other scientists.

Don Hyndman was the recent recipient of the 2021 High Plains Book Awards in Medicine and Science for Roadside Geology of Montana 2nd edition, by Donald W. Hyndman & Robert C. Thomas. He is a Fellow of the Geological Society of America and the American Geophysical Union, and is a Member of National Academy of Sciences panel on nuclear waste disposal.

In "retirement" he and his wife of many years, Shirley, travel extensively, in part to examine sites that illustrate natural hazards and disasters, and to write about them in his textbook on the subject.

GROUND WATER ASSESSMENT

Groundwater, often called the "hidden resource," is one of Montana's most valuable natural assets supplying domestic and municipal drinking water, irrigation and stock water, and sustaining streams and wetlands.

The Montana Ground Water Assessment Program is designed 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,
- 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 overseas 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



New West Crane aquifer irrigation well and monitoring well.

This past biennium, a unique partnership with the National Ground Water Monitoring Network (NGWMN) and the Yellowstone Controlled Groundwater area allowed the MBMG to secure funding to install a nested-monitoring well pair, strategically located between the town of West Yellowstone, the Madison River, and Yellowstone National Park. The shallow–deep well pair will monitor the unconfined and confined basin-fill aquifers in the Hebgen Basin that are

used for domestic and municipal water supplies. Data from these wells will help characterize the water quality in these aquifers, and monitor the effects of development, droughts, and other climate variability on groundwater levels.

Collaborative groundwater–surface water monitoring efforts between the MBMG and the Yellowstone Controlled Groundwater Area were also expanded along a reach of the Gallatin River between Yellowstone National Park and Big Sky, Montana. Seepage runs along the Gallatin River where it crosses the Madison Limestone were



Gaging the Gallatin River across a Madison Limestone outcrop.

conducted under baseflow conditions to assess potential recharge from the river to the underlying limestone aquifer (photo, left). Water-quality samples from the river and deep limestone wells were collected to investigate geochemical evidence of groundwater-surface water connections.

The Ground Water Monitoring Program is partnering with the Richland County Conservation District to provide technical oversight and assist in establishing a groundwater monitoring network in the West Crane aquifer near Sidney, Montana. This "buried valley" aquifer was formed when glacial deposits filled in an ancient river valley eroded into the Fort Union bedrock. Its existence was unknown 15 years ago, now it supplies more than a dozen high-capacity irrigation wells. The monitoring efforts will provide data for developing longterm aquifer management strategies (photo, above).

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 date, more than 9,400 wells have been visited and about 3,200 groundwater samples have been collected. These data have been used to compile 78 maps and reports that describe specific aspects of Montana's aquifers, groundwater flow systems, and groundwater quality.

This past biennium, in response to new health guidelines, manganese concentration in 3,854 groundwater samples from across the State were evaluated; most of the samples were collected by the Ground Water Characterization Program. Manganese, a naturally occurring element in groundwater, is a known "nuisance" constituent that can stain plumbing and laundry, and impart a bitter taste to water. However, emerging research indicates that elevated manganese concentrations in drinking water may be linked with adverse neurological outcomes. The Montana Department of Environmental Quality (MDEQ) has suggested the new human-health guidelines for manganese concentrations in drinking water (< 0.10 mg/L for those under 6 years old, and <0.30 mg/L for those over 6). The study showed that manganese concentrations were generally low: 85 percent of the samples were less than 0.10 mg/L (figure below); only 7 percent of samples exceeded the recommended health standard limit for adults and children over 6 years. Redox conditions and pH are strong controls on manganese solubility. The full report is available here: (https://mbmg.mtech.edu/mbmgcat/public/ListCitation.asp?pub_id=32448&).



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.

GWIC by the Numbers

- More than 47,220 unique users
- Currently about 4,100 sessions and 50,700 queries each month
- Information on 281,900 wells and boreholes
- Scanned images for 247,755 well log documents
- 59.6 million water-level measurements



New Hydrographs

The widespread deployment of new groundwater-monitoring instrumentation and sensor technologies generates large volumes of high-frequency data. With so much water-level data being collected, the GWIC hydrograph display was updated to present an efficient and clear picture of long-term trends. The new hydrographs present daily-average data to quickly display what can be decades of continuous data; new data-download options include daily average or the entire dataset for each site. Additionally, the hydrograph display includes a plot of the "departure from average precipitation" calculated on a quarterly basis for the climate region that well is located in. This display provides additional information and context to help identify, or explain, trends, patterns, and outliers in the water-level data.

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 year-round water source for household use and for livestock. Groundwater is also used for irrigated agriculture and provides baseflow to Montana's rivers. Changing land use and demographics can alter groundwater withdrawals, potentially affecting senior water rights holders, stream flows, the availability of irrigation water, and the health of aquatic ecosystems.

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

Current research questions include:

- Groundwater sustainability in response to increasing residential, irrigation, and commercial demands
- 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
- Changes in water quality due to increasing development
- Viability of developing buried river channel aquifers

The 2020–2022 Biennium

Four new GWIP project start-ups:

- Billings area, Yellowstone County—investigate groundwater availability and quality in the thin alluvial aquifer that serves as a water supply outside of the city limits.
- Eureka, Lincoln County—evaluate groundwater/surfacewater interactions and the effects of pumping on groundwater and surface water.
- Big Hole River, Silver Bow County—understand water quantity and temperature influences to the Big Hole River from irrigation return flow.
- Quantified irrigation recharge to groundwater—using sites in the Glen and Edgar areas to demonstrate the fate of applied irrigation water through the unsaturated zone and quantify recharge to groundwater.



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/)

GWIP hydrogeologists drilled the first well ever to penetrate the thickness of the deep aquifer in the Flathead Valley. At this location, the aquifer is 800 ft thick. An accurate measurement of aquifer thickness is critical for estimating the volume of water stored and transmitted through the aquifer.

Program Status

To date, over 100 projects have been nominated and prioritized by the Ground Water Steering Committee. Results are presented in public forums, question and answer opportunities, conferences, and published reports. Results of GWIP projects have been used in water-right permit decisions, water-resource development, and county planning.



Publications Released in 2020–2022

- Hydrogeologic investigation of the deep alluvial aquifer, Flathead Valley, Montana, Report of Investigation 32
- Aquifer tests completed in the Upper Gallatin River Valley, Big Sky, Montana, Open-File MBMG 750
- Hydrogeology and groundwater availability at Big Sky, Montana, 2022, Open-File MBMG 747
- An investigation of spring sources and potential alternative water supplies near Virginia City, Montana, 2022, Report of Investigation 30
- Hydrogeologic investigation of the Upper Jefferson River Valley, Madison and Jefferson Counties, Montana: Waterloo groundwater modeling report, 2021, Report of Investigation 29
- Hydrogeologic investigation of the Upper Jefferson Valley, Montana Interpretive report, 2021, Report of Investigation 28
- West Crane aquifer test summaries, Richland County, 2021, Open-File MBMG 737
- Hydrology and water management of the Clear Lake aquifer, 2021, Open-File MBMG 738
- Aquifer tests completed in the Bitterroot Valley, Hamilton area, 2021, Open-File MBMG 739
- Groundwater model of the Meadow Village aquifer at Big Sky, 2021, Open-File MBMG 742



Hydrogeologist Matt Smith measuring water levels in the Billings GWIP area. This project was nominated by the City of Billings because of concerns related to the capacity of the aquifer to meet increased development needs and to investigate the source of groundwater degradation.

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 five 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. USGS funding for mapping in Montana has significantly increased in recent years—from an annual award of \$163,000 in 2019 to almost \$649,00 for 2022. The increased funding has allowed the Mapping Program to hire two additional geologists and a full-time GIS analyst.

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 completion of 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 mapping in the west half of the Dillon and the east half of the Wisdom 30' x 60' quadrangles. Mapping in Dillon and Wisdom quadrangles is anticipated to be completed by 2024. Our work then shifts to northwest Montana.



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.

Recent mapping along the Big Hole River near Glenn (Block Mountain and Glen 7.5' quadrangles, Dillon Project Area) will provide the geologic framework for an irrigation return flow study currently in progress by the MBMG Ground Water Investigation Program. (Photo by Dave Pearson, Idaho State University). With the success of the program this biennium, the MBMG was able to hire several new geologists to join the team. New hires Stuart Parker and Dan Brennan joined the MBMG geologic mapping program in 2022. Patricia Ekberg, GIS Analyst, joined the program in 2021.





Stuart Parker.

Daniel Brennan.



Patricia Ekberg.

ECONOMIC GEOLOGY

The Economic Geology program at the MBMG has undergone significant growth and changes in the past few years. Economic Geologist Stan Korzeb retired in fall 2021. His replacement, Adrian Van Rythoven, comes from both academic and mineral exploration experience and joined the MBMG in May 2022. Adrian worked for 3.5 years developing the Bear Lodge rare earth element project in Wyoming. He also has experience in other commodities such as diamond, silver, and silica.

Another addition is Economic Geologist Kyle Eastman. Kyle has research and industry experience in Australia, Indonesia, and South America, and completed his M.S. at Montana Tech in 2017. Kyle's research interests include porphyry–epithermal–skarn mineralization and supergene processes.

With increasing geopolitical uncertainty, an inventory of domestic mineral resources has taken a larger position in the MBMG's current mandate. We are expanding our capabilities for resource assessment in terms of the number of samples we collect and what we examine them for. The MBMG is conducting a variety of expansive studies focused on the critical mineral resources present in mine waste, coalbeds, tailings, and other incompletely evaluated deposits within Montana.

These "critical minerals" are a collection of 50 commodities only three are true minerals (graphite, fluorspar, and barite), and the other 47 are elements (mostly metals). The federal government has designated these commodities as necessary to American industry and national security, as a high reliance on imports creates a risk of supply interruption.



Adrian Van Rythoven sits in front of the Bonanza Lode adit in September 2022 (mined for gold ca. 1918) in Silver Bow County. Photo credit: Tiffany Ostenburg, MBMG.

The MBMG has obtained new equipment to support these studies: handheld X-ray fluorescence analyzers, a petrographic microscope, and a radiometric spectrometer. The influx of samples and resulting data will be handled by expanding support facilities: sample curation, databases, and public web-based geographic information portals.

Based on the State's geology, particular critical minerals that Montana could (or already does) provide to the nation are: zinc, platinum-group elements (e.g., platinum, palladium), rare-earth elements (e.g., neodymium, dysprosium), graphite, tungsten, tin, barite, fluorspar, antimony, arsenic, bismuth, chromium, cobalt, gallium, germanium, indium, manganese, nickel, tellurium, titanium, and zirconium.

Funding for these critical mineral studies comes from a variety of sources, mostly federal (e.g., Department of the Interior, Department of Energy). A partnership between the U.S. Geological Survey and international mining conglomerate Rio Tinto led to a modern airborne geophysical survey of the Boulder Batholith in southwest Montana this summer. The results of this survey, designed with MBMG guidance, will be incorporated into a larger project that includes detailed geologic mapping and sampling completed by staff at MBMG.

Active Mining

• The critical minerals platinum and palladium (with lesser rhodium, nickel, and cobalt) are produced from the Stillwater Layered Mafic Intrusion by Sibanye–Stillwater's East Boulder and Stillwater mines in Sweet Grass County.

• Montana Resources produces copper and molybdenum from the Continental Pit, Butte District, Silver Bow County.

• Gold mining no longer occurs at Barrick's Golden Sunlight Mine in Jefferson County, but pyrite is being extracted from the tailings to remediate the risk of acid rock drainage at the site. The pyrite is then used in mineral processing at other Barrick mines outside of Montana.

• Coal mining occurs in six mines across four counties in central and western Montana. One mine produces lignite, whereas the others produce subbituminous coal.

Biennial Report 2020–2022

- Talc is mined at three mines across Madison and Beaverhead Counties.
- Over a dozen small-scale placer mines (gold and/or silver, or sapphire) operate across western and southwestern Montana.
- Small-scale hard rock sapphire mining continues at Yogo Gulch in Judith Basin County.
- Mining for specimens and gem rough (amethyst, smoky quartz) is ongoing at the Little Gem Mine, Jefferson County.
- Aggregate (sand and gravel), building stone, and limestone (cement) are quarried from a handful of locations, mostly in west-central Montana.

Active/Recent Exploration & Development

• Further exploration for platinum-group and other associated critical minerals in the Stillwater Complex is being conducted by Stillwater Critical Minerals (formerly Group Ten Metals).

• Rare-earth-element-bearing (a class of critical mineral) carbonatite deposits at Sheep Creek in Ravalli County are being evaluated by U.S. Critical Materials Corp.



MBMG Geologist Tiffany Ostenburg in front of the adit of the South Fork Parker Creek Phosphate Mine on the slopes of Mt. Fleecer. Photo by Adrian Van Rythoven.

• Sandfire Resources America (formerly Tintina Resources) is developing the Black Butte copper, silver, and cobalt project in Meagher County.

• Hecla Mining Company is evaluating the Rock Creek silver–copper deposit in Sanders County, and the Montanore silver–copper deposit in Lincoln County. Hecla also owns the nearby Troy mine that has been closed since 2015.



Adrian Van Rythoven takes notes while MBMG intern A. Harley Hoiles describes the host rock setting for a manganese deposit in Granite County. Photo by Tiffany Ostenburg, MBMG.

• Blackjack Silver Corp. is evaluating old underground mine workings in the Walkerville neighborhood of Butte (Silver Bow County) for silver, zinc, and copper.

- The Montana Tunnels silver–lead–zinc–gold mine in Jefferson County has been closed since 2008, and current plans to reopen by Montana Tunnels Mining Inc. have yet to receive environmental permits.
- American Pacific Mining Corp. is evaluating the Madison gold–copper project in Madison County. Recent drilling occurred with joint venture partner Rio Tinto in 2021.
- Brixton Metals and Ivanhoe Electric (formerly High Power Exploration) are conducting a joint venture to evaluate the Hog Heaven copper–gold–silver project in Flathead County.
- Winston Gold Corp. reports that it is very close to smallscale production from the underground Winston gold project in Broadwater County.

GEOLOGIC HAZARDS PROGRAM

The Geohazards Program characterizes and provides information on active faults, earthquakes, and landslides, and makes these data available to the scientific community, policy makers, emergency responders, and the public.

A major goal is to generate a statewide database of active faults and landslides. Successfully funded grants in FY 2021, 2022, and 2023 from the Federal Emergency Management Agency (FEMA) and the Montana Department of Emergency Services (DES) provided support to map active faults and landslides using Light Detection and Ranging (LiDAR) in several counties. Recent datasets from the newly available LiDAR surveys in Montana reveal numerous hazardous active faults and landslides that were previously unrecognized.

New MBMG geological maps showing the locations and age of displacement of hazardous faults and landslides are being released for Jefferson County or currently under review for Deer Lodge County. Fault and landslide maps are underway for Powell and Ravalli Counties. Map data are integrated into online geodatabases of statewide active faults and landslides. The current inventory of active faults and their geologic parameters will be published as geodatabases and made available through the MBMG Geohazards Portal to be used for earthquake hazard assessments and updates to the National Seismic Hazards Model. A web mapping application will allow users to visualize statewide Quaternary faults with LiDAR data and other available geohazards information (historic earthquakes, landslide occurrences, and liquefaction susceptibility).



LiDAR datasets for Jefferson County showing examples of hazardous landslides (left) and faults (right) with evidence of geologically recent displacement. Basemap is a slopeshade DEM (relief) derived from LiDAR data.

The Geohazards Program has also successfully acquired funding from the U.S. Geological Survey's National Earthquake Hazards Reduction Program (NEHRP) for field investigations of active faults. In 2020, MBMG geologists investigated the Bitterroot fault, an active fault located in the Bitterroot Valley. The project involved new geological and fault mapping using LiDAR to identify multiple fault scarps in recent glacial deposits. Fault slip rates on the Bitterroot fault were measured using Beryllium-10 cosmogenic radionuclide dating. Results from this study are provided in a technical report, a new 1:24,000-scale MBMG Geological Map, and an MBMG Bulletin.

From 2021 to 2022, the MBMG secured another NEHRP grant to conduct paleoseismological investigations of the Bitterroot fault. In September 2021, the MBMG led a project in collaboration with the USGS and Bureau of Reclamation to excavate the Bitterroot fault at Shannon Gulch, near the Como Dam. In September 2022, MBMG continued the paleoseismic investigation further north by excavating trenches at Camas Creek and Big Creek. The goal is to develop a Holocene chronology of paleoearthquakes to better understand the hazard of potentially damaging earthquakes in the Bitterroot–Missoula Valleys.



Drone photo of Bitterroot fault scarps. View is to the south showing that the gentle east-sloping Bitterroot Mountains front is controlled by an older Eocene detachment fault (background), and high-angle fault scarps in the foreground that offset old glacial lateral moraine deposits (Qgto) by ~75 m.

The MBMG hosted the Montana Geohazards Workshop at Montana Tech on April 28, 2022. The workshop brought together earth scientists, engineers, state agencies, local governments, various asset owners, and stakeholders to discuss geohazards and their potential risks to Montana and the broader Northern Rockies region. The meeting included staff from MBMG, FEMA, Montana DES, Montana Department of Transportation, Montana Department of Natural Resources, Zylient, University of Montana, Montana State University, Idaho Geologic Survey, Wyoming State Geologic Survey, and Utah Geologic Survey. The meeting provided an opportunity to present results from recent geohazards projects throughout Montana; identified research priorities and potential pilot collaborative projects with partner agencies; and discussed the need to establish earthquake and the Montana Seismic Safety Commission.

For more information about the workshop, see our website: https://www.mbmg.mtech.edu/MontanaGeology/geohazards/MontanaGeohazardworkshop.asp



Yann Gavillot in paleoseismic fault trenches across the Bitterroot fault. Left shows young lakebeds displaced and tilted by normal fault slip on the Bitterroot fault at Camas Creek (Sept 2022). Right shows an example of paleoseismic fault trench excavation at the Shannon Gulch site, near Lake Como (Sep 2021).

EARTHQUAKE STUDIES

Western Montana has a history of large, damaging earthquakes and remains seismically active. Most earthquakes (including the 1925 M 6.6 Clarkston earthquake centered north of Three Forks, and the M 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 44 seismic monitoring stations throughout western Montana, the most seismically active region of the State. The MBMG records data from 148 local and regional seismograph stations in real-time from 16 different networks, including data from eight USGS stations in Montana, four of which operate in eastern Montana. Other regional seismic monitoring centers in Utah, Idaho, Washington, and Canada exchange seismic data with the MBMG, which provides additional monitoring coverage near Montana's borders.

These seismic data are used to determine earthquake locations and magnitudes to create a seismicity catalog, which is also provided to the USGS National Earthquake Information Center. State, Tribal, 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 origin times, locations, and magnitudes for 7,241 earthquakes with magnitudes ranging from -1.1 to 4.9 from July 1, 2020 to June 30, 2022. This catalog, which extends back to 1982 and includes over 86,000 earthquakes, provides crucial data for assesing seismic hazards in Montana.



Epicenter locations for 7,241 earthquakes located by the MBMG from July 1, 2020 to June 30, 2022.

The largest earthquake in Montana during this period occurred on July 6, 2021 and was centered 38 miles ESE of Roundup. Citizens reported feeling this magnitude 3.6 earthquake in Billings and other locations closer to the epicenter. This unusual eastern Montana earthquake demonstrates that no region of Montana is completely immune from earthquake activity. In the much more seismically active western Montana, citizens reported feeling 40 earthquakes, including quakes in the magnitude 3.0 to 3.4 range centered near Boulder, Lima, Grant, Lincoln, Columbia Falls, Stryker, Hebgen Lake, Marysville, and Three Forks. The concentration of epicenters northwest of Helena are late aftershocks of the M 5.8 Lincoln earthquake that occurred on July 6, 2017. Hundreds of open-pit mine blasts are recorded annually and cataloged separately from natural tectonic earthquakes. The Montana seismic network records many Yellowstone earthquakes each year but the University of Utah is responsible for analyzing and reporting Yellowstone seismicity.

Most of the MBMG seismograph stations utilize outdated analog instrumentation (red triangles on seismic network map) that has been in service for decades and badly need updating. The MBMG recently received a DNRC Reclamation and Development Grant to purchase and install 10 new digital seismograph stations to upgrade the existing seismic network and enhance seismic monitoring coverage of the most active parts of Montana. This project should be completed by December 2024. To improve the density of seismic monitoring stations and enhance public outreach and education, the MBMG purchased 20 low-cost Raspberry Shake home seismographs. Most of these tiny seismographs have been provided to home owners and schools and join a network of over 1700 Raspberry Shakes operating globally (https://stationview.raspberryshake.org/).

Current seismograms from the MBMG network are available on the MBMG Earthquake Studies Office website (http://www.mbmg.mtech.edu/MontanaGeology/geohazards/main.asp), along with a listing of recent earth-



Seismograph stations recorded in real time at the Earthquake Studies Office and used to locate 2020-2022 earthquakes. Red symbols are seismograph stations operated by the MBMG; squares show modern digital stations while triangles show older analog stations. Black squares are stations operated by the US Geological Survey. Open triangles are stations operated by other networks including the University of Utah, Idaho National Labs, University of Washington, Idaho Geological Survey, Canadian Geological Survey, and Alberta Geological Survey. Open circles are Raspberry Shake stations hosted by homeowners and schools. Most of these within Montana were provided by MBMG.

ENVIRONMENTAL HYDROGEOLOGY

The Environmental Hydrogeology Program works with a variety of local, State, and Federal organizations providing technical assistance on a wide variety of groundwater and surface-water problems stretching from southwest Montana to far northeast Montana. The breadth of the geographic spread of projects is related to the diversity of Montana's economy, ranging from mineral extraction by underground and surface mining to ore processing to farming and ranching operations.

The MBMG, in cooperation with the Montana Technological University–Geological Engineering department, is assisting the U.S. Forest Service in the development of aerial drones for operation in abandoned underground mines where it is unsafe for personnel to enter due to lack of oxygen and/or safety concerns such as falling rocks or undetonated explosives. Several graduate and undergraduate students are developing low-cost drone platforms to perform a variety of tasks including mapping and modeling of underground workings, performing stability inspections, identifying sources of groundwater infiltration, and measuring underground oxygen concentrations. The cost of the drones needs to be reasonable since retrieval of a damaged or lost drone is not possible. Figure 1 shows a drone being deployed; figure 2 is an image from inside the mine taken from video collected during the drone's flight, and figure 3 shows the adit entrance of the Elkhorn Mine in the Beaverhead–Deerlodge National Forest.



Figure 1.





Figure 3.

Figure 2.

The MBMG is also working in northeast Montana with the Richland County-Conservation District, on a program to evaluate casing integrity in flowing wells and to develop plans to repair damaged wells and install frost-free hydrants. Numerous wells were drilled and installed into the Fox Hills–Hell Creek aquifer at depths greater than 1,000 feet. The wells were completed with 2-inch metal casing, which is starting to corrode in some instances. Due to continued drought and the long-term impact of large numbers of flowing wells, the discharge has either declined or stopped completely. This program aims to work with the Conservation District, landowners, and local contractors to

identify problem wells, provide repairs, and install frost-free hydrants. The MBMG performs an evaluation of casing integrity using a small-diameter downhole camera to video the inside of the casing to depths up to 1,000 feet. Figure 4 is a graph showing water-level declines over a period of almost 45 years in selected wells (a negative sign indicates distance above ground surface, based on pressure, that water would rise), while figure 5 shows a contractor assisting with well access.







Figure 5.

Current Projects

- Butte Mine Flooding Long-Term Monitoring
- Basin Watershed-Acid Mine Drainage (Bullion and Crystal Mines)
- Rocker Controlled Groundwater Area
- Butte Area Controlled Groundwater Program
- Mouat Superfund Site, Columbus, MT: Long-Term Groundwater Monitoring
- Berkeley Pit: Autonomous Sample Boat Program
- Elkhorn Mine: Underground Mine Drone Development for Safety Evaluation and Acid Mine Drainage Technical Assistance
- Glacier–Toole Co. Public Water Supply, Arsenic and Antinomy Sources
- Richland County Conservation District: Fox Hills-Hell Creek Flowing Well Evaluation and Rehabilitation
- Beal Mountain Mine Conceptual Site Model
- Determining Surface-Water Influences on Groundwater Upper Silver Bow Drainage
- Abandoned Mine Site Reports Preservation
- 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.

Despite the shift away from coal-fired power in the U.S., coal has the potential to remain a valuable commodity for the state of Montana. Nationally, new efforts are focused on identifying and extracting rare earth elements (REEs) and other critical minerals from coal resources. REEs possess unique properties that are essential to future technologies, including windmills, electric cars, and National Defense applications. The demand for these REEs over the next few decades is expected to increase significantly. Currently, most REEs are sourced outside of the U.S., leaving us vulnerable to supply shortages and price fluctuations. The MBMG, in collaboration with neighboring states, has launched several multi-year projects evaluating the potential of REEs in our coal deposits. These efforts are aimed at ensuring our Nation's mineral resource needs and the future economy of Montana.



Coal seam in McCone County.



Sampling a coal seam in eastern Montana.



Geologist Ryan Davison with an X-ray fluorescence spectrometer.

Hydrocarbon Investigation Program

MBMG's Hydrocarbon Investigation Program was established by the 2020 Montana State Legislature to conduct research facilitating the exploration and production of oil and gas in the State. Over the past 2 years, efforts have focused on building a foundation of information for exploration geologists searching for new oil and gas prospects, and for the citizens of Montana to learn about Montana's energy resources.

The Program's two current objectives are:

- Provide petroleum information and data in a publicly available web interface.
- Map the subsurface geologic formations in Montana's petroleum-producing regions.

Web Interface

The web map interface will allow users—Montana citizens, Federal and State agencies, lawmakers, and private industry—to access and query a variety of drilling, production, and related geologic information. For example, Montana's producing oil and gas fields are shown in the map below by irregular polygons (red, gas; green, oil; brown, oil+gas). The bubble size represents the cumulative production from oil (green) and gas (red) from each field.



Subsurface Mapping

Subsurface maps depict the structure (spatial position and extent), thickness, and reservoir characteristics of subsurface geologic formations. Knowledge of the geology below ground surface is critical for identifying potential hydrocarbon sources, traps, and reservoirs. These maps are also fundamental to understanding geologic hazards such as faults, identifying targets for wastewater or CO₂ injection, and managing and protecting groundwater aquifers.



This three-dimensional map shows elevation at the top of the Eagle Formation in the subsurface. The domed geologic structure forms an oil and gas trap —the "Poplar oil field" in Roosevelt Country. Colors represent elevation in feet.

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 spread public awareness of our preservation efforts and has led to the acquisition of 14 new collections. The development of more sophisticated digital processing expanded online archival information availability, and improved web delivery increased its use by government agencies, consulting firms, private geologists, and the public. Between July 2020 and June 2022, our webpage averaged 687 visits each month, totaling 857,000 searches that delivered 1.4 million records. Staff researched and responded to more than 140 information inquiries made in person, by telephone, or by email.



CollectionBuilder provides a cleaner and more navigable experience for users accessing various Data Preservation Collections.

Grants

The USGS National Geological and Geophysical Data Preservation Program (NGGDPP) awarded grant funding (100% matching funds are required) to support the following efforts for data rescue and preservation of data.

• We are inventorying and digitizing 301 historic stope books for underground mines in the Summit Valley (Butte) Montana Mining District. These one-of-a-kind books compile mining and geologic data collected from the 1880s to 1982. Each book presents detailed maps of each layer of a particular mine. This project builds on a previous NGGDPP grant-supported project and will provide public access to scans of all 349 known stope books.

• Data Preservation staff inventoried, photographed, and provided digital access to the Anaconda Research collection of nearly 12,000 rock/mineral specimens and related information curated by the geologic research department of the now-defunct Anaconda Mining Company. The collection contains hand samples, drill core, thin sections, and polished sections collected from mines in Montana, the western United States, and South America mainly between 1940 and 1981.

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 Montana Department of Environmental Quality to digitize their archived geologic, hydrogeologic, and mine engineering data related to abandoned mine lands. Preservation of the data includes inventory, scanning, and digital restoration of documents, reports, and maps related to mine reclamation and remediation. This project makes these important documents more visible and accessible to the public.

• Butte–Silver Bow (BSB) Government: We continue to provide 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.

Direct Support of Education

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

We collaborated with the non-profit Career Futures to employ an Environmental Studies student intern from UM Western. This student acquired work experience in Data Preservation and several other MBMG program groups.

New Donations

The MBMG accepted donations of 14 Montana-related historical mining and geophysical collections. The donations vary in size and include reports, maps, specimens, and drill core received from mining companies, other state surveys, universities, and geologists from throughout the U.S.

Economic Geology Support

Critical Minerals

The MBMG was again awarded funding through the NGGDPP grant to continue identifying and evaluating mineral resources in Montana. Data Preservation staff provide ongoing support for this critical mineral research. *Oil and Gas*

We previously received two large oil and gas exploration collections, the Virgil Chamberlain and M.K. Jones collections. One of our student employees in Petroleum Engineering assisted with creating an inventory of both.

Significant collections added to our archived oil and gas information include:

- o Lafayette Poole's family donated 129 oil and gas exploration maps.
- o Earl Norwood's estate donated maps and logs generated during his career as a petroleum geologist.
- o Geophysicist Wayne Ewert's family donated over 1,000 maps, reports, and seismic sections for eastern Montana.
- o Orphan core butts from Stratum–Arvada and supporting data such as core gamma logs and core analyses were rescued and donated to the MBMG.

Uranium

We scanned drill logs from 528 holes. Bringing this information out of storage and making it publicly available can potentially foster new development.



The newly added Zeutschel book scanner allows us to scan rare or fragile materials without damaging them.

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.



Clear Lake Aquifer Study

The Clear Lake aquifer is an important water resource in northeastern Montana. The aquifer is contained in buried valleys underlying broad topographic swales associated with the ancestral Missouri River and glacial meltwater channels. The MBMG has assisted the Sheridan County Conservation District (SCCD) in increasing their understanding of hydrogeologic conditions of the aquifer, developing tools to better manage the water reservation, and ultimately determining the maximum development capacity of the aquifer. The mapping and monitoring associated with this work have provided the scientific background to steadily increase irrigation water development of this aquifer since the Clear Lake Water Reservation was authorized under the SCCD. A Technical Advisory committee consisting of State, Federal, Tribal, and local entities reviewed and recommended new appropriations initially capped at 5,809 acre-ft, increased to 10,000 acre-ft in 2004, and potentially increasing to a total of 15,479 acre-ft. Local water management has proven to be an effective method of irrigation development.

Musselshell River Study

Salinity characterization of the Musselshell River and its tributaries by the Montana Department of Environmental Quality identified streams that may be impacted by historical oil and gas development in Musselshell County. Oil and gas produced brine migration is hypothesized to be the source of elevated levels of salinity in North Willow Creek and perhaps other small tributaries to the Musselshell River. The Montana Bureau of Mines and Geology, with funding through the DNRC RRGL program, has implemented a groundwater and surface-water sampling program to analyze major ion characteristics, isotope fingerprints (carbon and strontium isotopes), and organic constituents (diesel range and gasoline range organics) of the groundwater and surface water of the area. The water chemistry data will be used, along with information related to geology and soils, to delineate the sources of elevated salinity identified by the DEQ.



North Willow Creek.

Measuring Groundwater Recharge in Flood to Pivot Irrigation Conversions



Flood and pivot irrigation both visible in this field, near Edgar, MT.

The economic and conservation benefits of pivot irrigation are convincing many Montana irrigators to install sprinkler irrigation systems that allow for more precise management of water and soil and require less operator time. For maltbarley and sugar beet growers in southcentral Montana there is specific pressure from retailers to demonstrate water conservation. However, rural residents rely on irrigation-recharged groundwater for domestic water. Reduced aquifer recharge as a consequence of more efficient irrigation will impact groundwater supplies and, in some locations, baseflow to streams.

The Montana Bureau of Mines and Geology (MBMG), in cooperation with Carbon County, the USDA Natural Resources and Conservation Service, Montana Department of Natural Resources and Conservation (DNRC), and private landowners are monitoring irrigated field sites that have historically been flood irrigated but are—or will

be—converted to pivot irrigation. The MBMG will use the results from this research to understand the field characteristics that are important to ensuring groundwater availability. This information will be provided to irrigators for consideration when choosing field sites for pivot installation.

GIS LABORATORY

The Geographic Information Systems (GIS) Lab hired a new GIS Manager in February 2022. With this new hire, the focus of the GIS Lab is shifting towards enterprise level data management and modernization of GIS applications for both internal staff and public access to the MBMG data.

The MBMG has long had large and complex databases of geologic and hydrogeologic data. The main focus going forward is to make that data available to staff and to the public in GIS format. Translation of the data into ArcGIS enterprise level databases began in February 2022, and the GIS team has made significant strides in spatializing data that was otherwise only available in tabular fashion.

The goals of spatialization of data, the enterprise data management process, and modernization are to be able to create 2D maps, 3D maps, and statistical and analytical dashboards that will better visualize the MBMG data in a more modernized and scientific look and feel. ESRI states that 65% of people understand data better when they can visualize it, whether as maps or as charts and graphs. In 2022 the GIS staff have built 20+ new applications as web maps, in both 2D and 3D space, and as a suite of analytical dashboards that allow for a statistical look at our data.



Part of the modernization process is to provide better and more streamlined access for our public constituents. We want the public to have easier access to our maps, apps and data. MBMG's new GIS Open Data Hub Site, built on the ArcGIS Hub Site platform, is planned for release soon. The "Hub" site for GIS is exactly that, a one stop shop for all web maps, analytical dashboards, and story maps, along with direct download access to the MBMG GIS data.



ANALYTICAL LABORATORY

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 δ^{13} C High-Precision Isotopic carbon dioxide (CO₂) analyzer, G2131-i for ¹³C isotopic analysis of CO₂ in water; a Costech Combustion Module was added to the Picarro G1231-i to allow for ¹³C 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

Over the past two years the MBMG Laboratory has analyzed thousands of samples, both from MBMG projects and research efforts from MT Tech and other MUS schools. The graphs below show comparisons of total samples received per year, the number of samples that are for MBMG projects vs. non-MBMG research, and research samples coming from Montana Tech vs. other MUS schools.



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 9,500 visitors, including 39 tour groups, composed of 1,090 adults. Representatives from the Mineral Museum attended Denver Mineral show in 2021 and the Butte Mineral Show in 2021 and 2022. Over this biennium, the Mineral Museum accessioned 36 new specimens further building out the mineral collection.

Through the Generations



Bust of William Clark, one of Butte Montana's Copper Kings (left). The Clark Family donated a large collection on display in the museum, including a rhodochrosite sample from the Emma Mine in Butte (bottom right). This collection is of particular interest to multiple generations of Butte locals (top right), proud of the town's history and legacy in natural resource development. Photos: Steve Quane, MBMG.

Looking to the future, the MBMG held a search for a new position of Mineral Museum Director to start in the following biennium. In part, the position was created to raise awareness of the State's natural resources through the creation and promotion of outreach programming and hosting of meetings, workshops and symposia. In addition, the new Director will design and implement thematic, high-quality displays in the Mineral Museum and public areas throughout the State.





A crowd favorite for all ages is our collection of fluorescent minerals seen under white light (left) that glow under shortwave UV light (right), including a sample of hyalite opal and a sign made by the addition of powdered fluorescent minerals to highlight the collaboration between Montana Tech and the Mineral Museum. Photo: Steve Quane, MBMG.



This summer, the MBMG Ground Water Assessment Program led a cooperative effort to drill and instrument a nested pair of observation wells on the Blackfeet Reservation. The drillsite team included representatives from the Blackfeet Water Department, MBMG, USGS, and O'Keefe Drilling.



Kerrie Mueller, Missoula Valley Water Quality District Big Sky Americorps member, collects a spring precipitation sample from Lolo Pass as part of the work of the Montana Precipitation Isotope Network, a pilot project the MBMG is collaborating on.



Dillon Ewert, a student employee with our Data Preservation program, scanning and preserving historic information that can help with future energy and mineral development throughout Montana.

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 141, Genesis and exploration potential for Late Cretaceous veins of the Big Foot mining district, Korzeb, Stanley L., Jefferson County, Montana, 2020

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- DIGITALPUB 3, Digital structure map of the Eagle Formation, central and eastern Montana, Gunderson, Jay A., 2020
- DIGITALPUB 4, Liquefaction susceptibility in Montana, Li, Y., Stickney, M., Sadeghi, M., Yakovlev, P., and Thale, P., 2021

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EDMAP 14, Surficial geologic map of portions of the McGregor Peak, Murr Peak, Marion, and Hubbart Reservoir 7.5' quadrangles, Flathead County, Montana, Montejo, Carlos, 2021

Geologic Maps

- GM 79, Geologic map of the Foolhen Mountain 7.5' quadrangle, Beaverhead County, Montana, Elliott, C.G., and Lonn, J.D., 2021
- GM 80, Geologic map of the Virginia City 7.5' quadrangle, Madison County, Montana, Mosolf, Jesse G., 2021
- GM 81, Geologic map of the Eli Spring 7.5' quadrangle, Beaverhead County, Montana, Mosolf, Jesse G., 2021
- GM 82, Geologic map of the Henderson Ridge quadrangle, Lemhi County, Idaho, and Ravalli County, Montana, Lewis, R.S., Burmester, R.F., Lonn, J.D., Stewart, D.E., and Canada, A.S., 2021
- GM 83, Geologic map of the southern Bitterroot fault, Bitterroot Valley, western Montana, Lonn, J.D., and Gavillot, Y.G., 2022

Ground-Water Atlas Series

- GWAA 6-04, Groundwater quality of Carbon and Stillwater Counties, south-central Montana, LaFave, J.I., and Carstarphen, C., 2022
- GWAA 8-04, Potentiometric surface in Gallatin, Lower Madison, Lower Jefferson, and Upper Missouri River Valleys within parts of Madison and Gallatin Counties, Montana, Madison, James P., 2022

Information Pamphlets

IP 13, West Crane buried valley aquifer: A hidden resource, Chandler, K., and Reiten, J., 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 732, Hydrogeology of the Rock Creek Benches, Carbon County, Montana, Reiten, J., 2020
- MBMG 733, Hydrogeologic investigation of the Stevensville study area, Ravalli County, Montana: Interpretive report, Waren, K., Myse, T., Snyder, D., and Abdo, G., 2020
- MBMG 734, Madison aquifer test: Prairie Nest irrigation well, Great Falls, Montana, Chandler, K., Kuzara, S., and Reiten, J., 2020
- MBMG 735, Hydrogeologic investigation of the Four Corners area, Gallatin County, Montana: Interpretive report, Michalek, T., and Sutherland, M., 2020



Biennial Report 2020–2022

- MBMG 736, Butte Mine Flooding Operable Unit water-level monitoring and water-quality sampling 2019 consent decree update, Butte, Montana, 1982-2019, Duaime, T.E., McGrath, S.F., Icopini, G.A., and Thale, P.R., 2021
- MBMG 737, West Crane aquifer test summaries, Richland County, Montana, Reiten, J., and Chandler, K., 2021
- MBMG 738, Hydrogeology and water management of the Clear Lake aquifer, with emphasis on the South Medicine Lake management area, Reiten, J., and Chandler, K., 2021
- MBMG 739, Aquifer tests completed in the Bitterroot Valley, Hamilton, Montana, Myse, T., and Snyder, D., 2021
- MBMG 740, Granite Mountain Mine--Deep bedrock well installation and evaluation: Butte, Montana, Duaime, T.E., and Icopini, G.A., 2021
- MBMG 741, SNaP: A survey of native proppant resources within Montana, Getty, J.C., Koracin, N.V., and McDonald, C., 2021
- MBMG 742, Groundwater model of the Meadow Village aquifer at Big Sky, Montana, Waren, K., Rose, J., and Breitmeyer, R., 2021
- MBMG 743, Yellowstone Controlled Groundwater Area, Montana long-term monitoring program: Data summary report, English, A., LaFave, J.I., and Richter, M., 2021
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- MBMG 745, Butte Mine Flooding Operable Unit water-level monitoring and water-quality sampling 2020 consent decree update Butte, Montana, 1982-2020, Duaime, T.E., McGrath, S.F., Icopini, G.A., and Thale, P.R., 2021
- MBMG 746, Standard procedures and guidelines for field activities, Montana Bureau of Mines and Geology, Edited by Madeline B. Gotkowitz, 2022
- MBMG 747, Hydrogeology and groundwater availability at Big Sky, Montana, Rose, J., and Waren, K., 2022
- MBMG 748, Dissolved methane in Powder River Basin groundwater, Meredith, E., and Sasse, D., 2022

Information Services Statistics Publication Sales:

- 741 titles sold
- 5,752 items sold
- 40 items published/released

Data downloaded:

- 3,573 titles
- 337,635 files

MBMG 749, Basin watershed monitoring data summary report, 2016-2020, Duaime, T.E., and Icopini, G.A., 2022

Miscellaneous Contributions

- MC 22, Technical reports completed for the National Ground-Water Monitoring Network, 2015--2019, LaFave, John I., 2020
- MC 23, Technical reports completed by Montana Technological University's Geophysics Field Camp near Virginia City, Montana, Compiled by Andrew L. Bobst, 2022



- MISC 69, 2021 MBMG Calendar: Smith River, English, Alan R., 2020
- MISC 70, 2022 MBMG Calendar: Dinosaurs in Montana Horner, Jack, 2021

Reports of Investigation

- RI 27, Hydrologic investigation of the Upper Jefferson River Valley, Montana: Whitehall groundwater modeling report, Gebril, A.F., and Bobst, A.L., 2020
- RI 28, Hydrogeologic investigation of the Upper Jefferson Valley, Montana--Interpretive report, Bobst, A.L., and Gebril, A.F., 2021
- RI 29, Hydrogeologic investigation of the Upper Jefferson River Valley, Madison and Jefferson Counties, Montana: Waterloo groundwater modeling report, Gebril, A.F., and Bobst, A.L., 2021
- RI 30, An investigation of spring sources and potential alternative water supplies near Virginia City, Montana, Bobst, A., Michalek, T., and Mosolf, J., 2022

Special Publications

- SP 122, Geology of Montana—Volume I. Geologic History, and Volume II. Special Topics, in process: released papers available here: http://www.mbmg.mtech.edu/pubs/GeologyofMontana/
- SP 123, Proceedings of the Montana Mining and Mineral Symposium 2021, Scarberry, K.C., Gammons, C.H., and Barth, S., editors, 2022



MBMG GRANTS AND CONTRACTS (NEW)

in effect during this biennium

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 Downey, J., Williston Basin CORE-CM, University of North Dakota Duaime, T., Domestic Well Program, Butte Silver Bow Duaime, T., Butte Priority Soils Groundwater Sampling, 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., Stream Flow Monitoring, Montana Resources Duaime, T., Granite Mountain Mine Well Replacement, Montana Resources Duaime, T., Elkhorn Mine and Mill, U.S. Department of Agriculture–Forest Service English, A., Yellowstone Controlled Ground Water Area, U.S. Department of Interior–National Parks Service Gavillot, Y., Bitterroot Fault–Quaternary Slip Rates, U.S. Geological Survey Gunderson, J., Powder River Basin CORE-CM, University of Wyoming Gunderson, J., Williston Basin CORE-CM, University of North Dakota Icopini, G., Rocker Controlled Groundwater, MT Department of Environmental Quality Icopini, G., Belt Technical Assist., 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., Clear Lake Aguifer, Sheridan County Conservation District LaFave, J., Karst-Bearing Limestone Recharge, 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 LaFave, J., Water Center, MT State University, U.S. Geological Survey 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., Reducing Mobilization of Oil-Brine Salt to Streams, MT Department of Natural Resources and Conservation Meredith, E., EPSCoR CREWS, National Science Foundation via University of Montana Metesh, J., Montana's Seismic Hazards, MT Disaster and Emergency Services Metesh, J., Earthquake Hazards Reduction, MT Disaster and Emergency Services Mosolf, J. National Geological and Geophysical Data Preservation Program, U.S. Geological Survey Scarberry, K., Earth MRI, U.S. Geological Survey Scarberry, K., Data Preservation, U.S. Geological Survey Scarberry, K., National Geological and Geophysical Data Preservation Program, U.S. Geological Survey Stickney, M., Flathead Seismic Monitoring, Confederated Salish & Kootenai Tribes

Timmer, J., Montana Pole Plant Analytical Services, MT Department of Environmental Quality

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 39 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 2021 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 groundwater program. Many of the projects under contracts and grants rely on partial state support (matching funds). Although below historic levels due to the completion of large Superfund-related projects, this biennium shows the beginning of what may be a moderateterm expansion of Federal funding opportunities.





Montana Bureau of Mines and Geology



Computer Services and Geographic Information Systems

Jeff Johnson, Computer Support Specialist III John Sanford, Associate Professor, GIS Manager Patricia Ekberg, GIS Specialist Yiwen Li, Professional Scientist, GIS Specialist

MBMG STAFF

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Retirees

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. Eugene (Igan) Graf IV, Developer, Bozeman—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

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Mr. Robert Wintergerst, U.S. Forest Service

Yellowstone Controlled Ground Water Area Technical Oversight Committee

- Mr. Attila Folnagy (chair), Department of Natural Resources and Conservation
- Mr. John Kilpatrick, U.S. Geological Survey
- Mr. Marvin Miller, Montana Bureau of Mines and Geology
- Mr. David Susong, USGS for National Park Service
- Mr. Kirk Waren, Montana Bureau of Mines and Geology (retired)

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





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