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BIANNUAL REPORT OF ACTIVITIES AND PROGRAMS OF THE MONTANA BUREAU OF MINES AND GEOLOGY JULY 1, 1988-JUNE 30, 1990

compiled by
Edward T. Ruppel

OPEN-FILE REPORT 232 1990

Montana Bureau of Mines and Geology
A Department of
Montana College of Mineral Science and Technology

Open-File Report 232

Biennium Report of Activities and Programs of the Montana Bureau of Mines and Geology July 1, 1988-June 30, 1990

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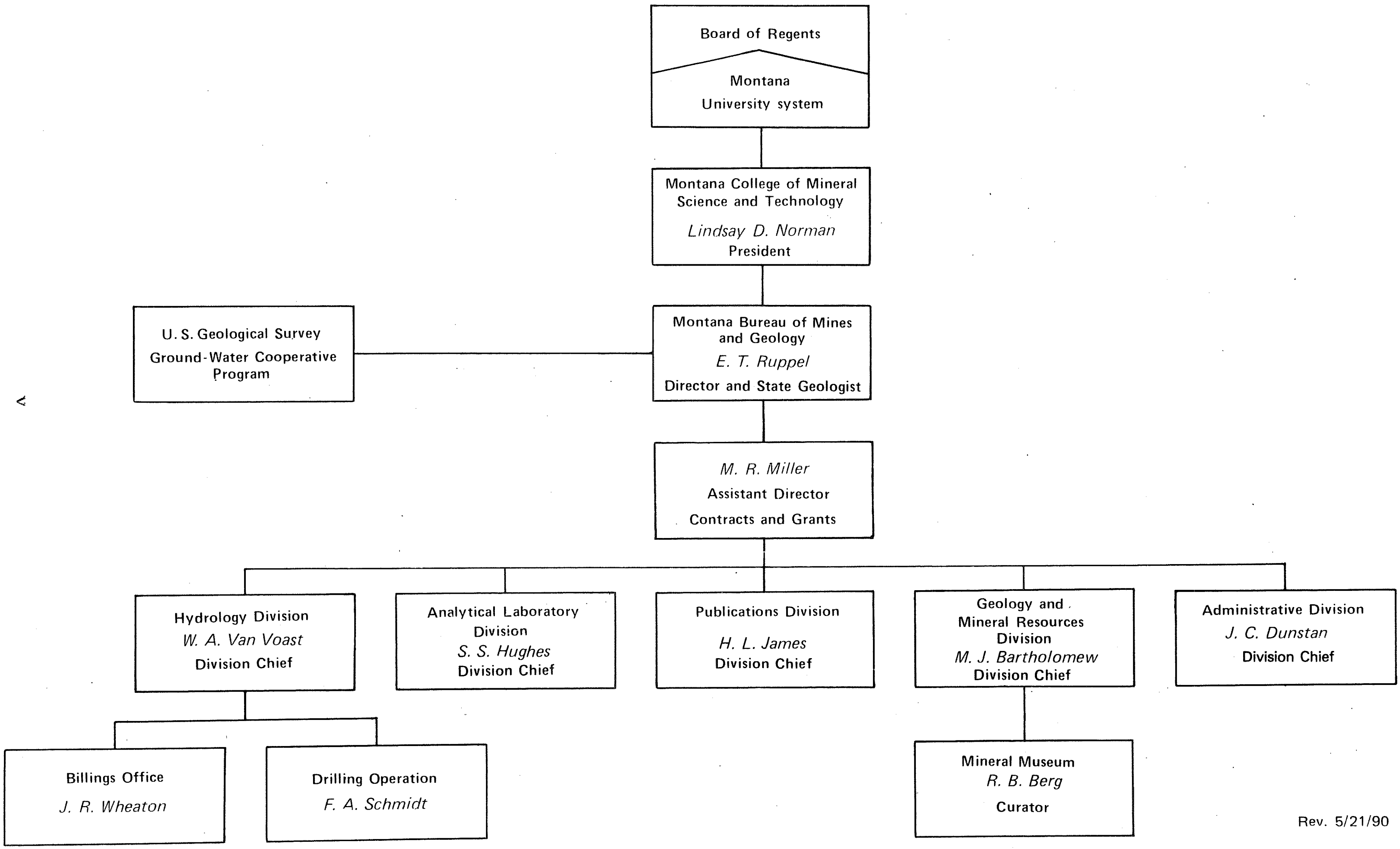
MONTANA BUREAU OF MINES AND GEOLOGY
ORGANIZATION CHART, 1988-90



Biennial Report

1988-1990

Edward T. Ruppel

Director and State Geologist

Introduction

The Bureau of Mines and Geology, a public service agency and research entity of the Montana College of Mineral Science and Technology, is the only earth science research agency in Montana State Government, and is responsible for assisting in the orderly development of the State's mineral, energy and groundwater resources. The agency gathers, field tests, analyzes, catalogs and disseminates mineral energy and groundwater information.

According to Section 75-607, R.C.M., 1947, Amended as enacted by the Legislature of the State of Montana, the object and duties of the Montana Bureau of Mines and Geology shall be the following:

(1) To collect, to compile and to publish statistics relative to Montana geology, mining, milling and metallurgy.

(2) To collect typical geological and mineral specimens and samples of products; to collect photographs, models and drawings of appliances used in the mines, mills and smelters of Montana.

(3) To collect a library and a bibliography of literature pertaining to or useful for the progress of geology, mining, milling and smelting in Montana.

(4) To study the geological formations of the State, with special reference to their economic mineral resources, both metallic and nonmetallic, and with special reference to ground water.

(5) To examine the topography and physical features of the State, with reference to their practical bearing upon the occupation of the people.

(6) To study the mining, milling and smelting operations carried on in the State, with special reference to their improvement.

(7) To prepare and to publish bulletins and reports, with necessary illustrations and maps, which shall embrace both a general and a detailed description of the natural resources and geology, mines, mills and reduction plants of the State.

(8) To make qualitative examination of rocks and mineral samples.

(9) To consider such other scientific and economic problems as in the judgment of the State Board of Education (Board of Regents) are of value to the people of the State.

(10) To communicate special information of Montana geology, mining and metallurgy.

(11) To cooperate with the other departments of the Montana University System, with the State Mine Inspector, and with other departments of the State government, as may be mutually beneficial; and to cooperate with the United States Geological Survey and with the United States Bureau of Mines, in accordance with the regulations of those institutions.

(12) It shall also be the duty of the Montana Bureau of Mines and Geology, upon the request of the Department of State Lands, to make examinations of State lands with regard to their geological formation and structure and as to all features relating to the character, extent and probable value of mineral deposits therein, including oil and gas; provided, however, that these services by the Bureau shall be limited to the time that its personnel has available for such work in addition to its duties as defined in the preceding sections. Written reports may be prepared of the examinations made.

Subject to the same limitations and conditions as above enumerated, the Montana Bureau of Mines and Geology shall carry on field examinations for other branches and agencies of the government of the State.

In fulfilling these duties, the Bureau provides extensive advisory, technical and informational services on the geology, mineral, energy, and water resources of Montana. These services are used by a wide range of Montana citizens, by other Montana State agencies, and county and local governments, by federal agencies, and by a large number of out-of-state private citizens and corporations. Several thousand requests for information on Montana geology, earth and water resources commonly are received each year.

In addition, the Bureau of Mines and Geology conducts basic and applied research on regional geology and hydrogeology, mineral and energy resources, earthquakes and related geologic hazards, landslides, ground and surface water resources and water quality, coal hydrogeology, and on other related topics. Many of these studies are conducted jointly with other state and federal agencies and with county governments, municipalities, and other local groups. These studies reflect the Bureau's commitment to provide timely and appropriate information on geology, hydrogeology and earth resources.

The geologic program is centered in the Bureau Geology and Mineral Resources Division. In the 1993 Biennium, Bureau geologists will concentrate most of their efforts on geologic studies that will contribute to a new state geologic map, a cooperative project with the U.S. Geological Survey. The ultimate goal of the work is a new geologic map of Montana to replace the current map that is almost 40 years old, out-of-date and out-of-print. The new map will show the major advances made in understanding Montana's geologic framework since 1950, and will be an important tool for finding and developing new sources of minerals, energy resources, and groundwater, in outlining areas of geologic hazards like landslides and earthquakes and areas of environmental concern.

In the 1993 Biennium, about one-fourth of the State will be mapped in reconnaissance for the State geologic map project at 1:500,000 scale. In addition, the Glendive and Belt quadrangles (1:100,000) and the Lincoln Gulch, Graphite Mountain, Dixon Mountain and Dell quadrangles (1:24,000) are planned for completion and publication. The Home Park Ranch and Spur Mountain quadrangles (1:24,000) will be completed and prepared for publication, and compilation of the Lima quadrangle (1:100,000) will be started. A study of metamorphic rocks and gold veins in the Virginia City area will be completed.

Bureau geologists will continue studies of non-metallic and metallic mineral resources, particularly in areas being mapped. The Staff Field Agent will systematically visit operating mines throughout the State, will continue to expand the Montana Mine and Mineral Data System as time and funds permit, and will continue a newly begun study of the economic benefits and impacts of mining on nearby communities and counties. The Staff Field Agent will publish annual reports on mining and mineral developments in Montana, and will begin publication of a new annual report, Minerals and Montana, that will report on the contributions that the mineral industry makes to local, regional and state-wide economies.

In continuing studies of geology-related hazards, a map (1:500,000) of landslides in the State will be published, and the Earthquake Studies Office will continue to monitor and record earthquakes in the western part of the State. Efforts to expand the Bureau seismic network will be continued at a planned rate of at least one new seismic station per year if funding permits. A book containing about six reports on young faulting, earthquakes, and related subjects in southwest Montana will be published in Fiscal 1992.

Under the Mineral Resources Program the long-term USGS-MBMG cooperative National Coal Resources Data System (NCRDS), the Montana Mine and Mineral Data System, and the Assistance to Small Miners are the principal ongoing information and assistance projects. The first coal-resource-evaluation of a 1:100,000 quadrangle (Sidney), a new 1:500,000-scale map and report on placer gold, a multipaper volume on Montana coal and summaries of mining techniques and mining economics for active mines in Montana will be published during the next biennium.

Under the Educational Program, Bureau geologists and engineers will continue to teach both formal courses at Montana Tech and short courses on prospecting and mining as well as lectures to various groups around the State. Bureau geologists curate both the Mineral Museum and the Mineral Research collection at Montana Tech.

The Bureau of Mines and Geology strongly supports the National Geologic Mapping Program initiative that soon will be submitted to the United States Congress. The NGMP proposes greatly enlarged geologic mapping efforts, in response to the wide need for geologic maps that currently is not being met. If the Congress passes and funds the initiative, Federal matching funds for new geologic mapping in Montana could be available in Fiscal 1993, to enhance the already strong geologic mapping efforts in the Bureau. A cooperative mapping program in Kentucky has shown a return to the State of more than 50 dollars for each State dollar expended. A similar return can clearly be expected in Montana, where the most common request in the Bureau Sales Office is for new geologic and hydrologic maps, and where the most basic data needed for State GIS compilations is geologic and hydrologic data.

The groundwater program is centered in the Bureau Division of Hydrology. Most hydrogeologic research in the Bureau is carried on in cost-sharing cooperative projects with Federal and State agencies and other users. In the 1993 Biennium, Bureau hydrogeologists will continue to expand the Groundwater Information Center (GWIC) established by the Legislature in 1985, and plan to make the Center more responsive to public needs by distributing groundwater information to water-data users on microprocessor based discs. Establishing continuous funding support for the GWIC is a major objective, so that the water information can be dependably and routinely stored and distributed. Basic data and updated information will be housed in the Bureau Prime computer, which will continue to provide groundwater data for all users. Bureau hydrogeologists will continue to help those users who need assistance in interpreting hydrologic data. The Bureau will continue to actively cooperate with the Montana State Library in disseminating water-resources information.

Utilizing the GWIC and some newly acquired computer capabilities, the Hydrology Division will begin providing information on water resources through Geographic Information System (GIS) technology. This technology enables graphic presentation by maps or charts of all information stored in the GWIC. It has become one of the foremost techniques for land-use planning, resource evaluation, and environmental assessment. The first Bureau GIS project will be completed in late 1991, and will graphically provide State-wide water resources data for the Montana Department of Health.

Bureau hydrogeologists will expand their activities addressing the problems of agricultural chemicals (fertilizers and pesticides) in Montana groundwater. In addition to studies characterizing the presence of agricultural chemicals in groundwater, a program of public information and awareness at chemical storage and handling sites will be initiated. This program will describe the vulnerability of rural-community water supplies to pollution, and will be intended to reduce the potential of contamination of shallow aquifers.

Studies and monitoring will continue on the distribution and mobility in groundwater of soluble salts in coal overburden and mine spoils, and on groundwater quality and movement near surface coal mines. Ultimate goals are determining how quickly soluble salts are removed or stabilized after coal mine reclamation, and on determining local and regional impacts of coal mining on disturbed or adjacent aquifers. Predictive techniques for water-quality degradation by new mines have been developed from the Bureau's work, and will be refined during the 1993 Biennium. The techniques will be used in planning of mining and reclamation to minimize the long-term effects on water.

Research on saline seeps in the Rapelje area will continue, as will numerous local projects on rural-community water supplies and on bottled water businesses. Because of severe drought and/or increased water needs, numerous Montana communities are experiencing critical water shortages and have requested assistance from Bureau hydrogeologists. The Bureau will continue to provide information and assistance as needed.

Participation in investigations and monitoring programs in cooperation with the International Joint Commission and other Federal agencies will continue. Specifically, a ten-year summary of the Poplar River Monitoring project is planned to be completed by 1991.

A highly technical evaluation of groundwater development for irrigation begun in late 1989, will continue through 1991. This study addresses water quality and quantity in abandoned underground coal mines near Roundup, and the feasibility of using the 15,000 acre-ft of mine voids as a vast underground reservoir for storage of irrigation water. This project is considered by some to be the last remaining large-scale potential groundwater development in Montana.

In cooperation with EPA, State Department of Health, and other organizations, Bureau hydrogeologists are actively involved in several projects relating to potential impacts caused by hard-rock mining and pole treatment industries in the Clarks Fork River Basin. Projects include: monitoring water levels and geochemical changes in the Berkeley Pit, nearby mine shafts, and adjacent observation wells; evaluating effects of metal loading to Silver Bow Creek and its tributaries as a result of storm runoff and groundwater inflow; investigating the movement of toxic elements in soils damaged by metal-rich irrigation water and/or airborne smelter fall-out; and characterizing the movement, distribution, and removal of pentachlorophenol from contaminated soil and groundwater. Long-term monitoring of streams, wells, and shafts, as well as repeated sampling for chemical changes are required to evaluate hydrologic trends and changes but preliminary results and/or interim reports are anticipated for each of the projects during the next biennium.

Several projects will be conducted that relate to hydrologic aspects of petroleum and coal exploration. Among these are a study of oil-field brine contamination of shallow aquifers in Sheridan County, and a project experimenting with new methods to accomplish hydrologically-safer plugging of seismic shot holes and coal exploration holes. As with all Bureau water studies, objectives are to develop understanding of the problems, and then to develop means of reclaiming mitigating, or avoiding future ones.

A cooperative program initiated in 1990 between the Bureau and the Montana Department of State Lands, Reclamation Division, has been so successful that it will be continued at least through the 1993 biennium. Through sharing of manpower, travel and funds, the agencies are cooperatively evaluating hydrologic aspects of mines, permit applications, monitoring programs and reclamation plans.

A newly begun project to artificially induce groundwater recharge will also be conducted over the next biennium. In cooperation with the U.S. Bureau of Reclamation and the Montana Department of Natural Resources, Bureau scientists are investigating and experimenting on the Turner-Hogeland Bench by utilizing enhanced snow-accumulation and snow-retention measures to recharge a shallow aquifer historically prone to overdrafts from irrigation.

The Bureau and the U.S. Geological Survey have a small, but active groundwater coop program in which the USGS, with matching funds from the Bureau, undertakes selected hydrologic investigations and supplements the Bureau's data collection efforts. Current active projects include: streamflow evaluations of Silver Bow Creek in conjunction with Bureau groundwater studies; groundwater monitoring at key locations State-wide; streamflow measurement and sampling on the Poplar River downstream from Saskatchewan coal and powerplant facilities; and a study of groundwater occurrence and quality in the oil-field pollution prone Sweetgrass Hills area.

Few of the water-resources projects described above could be accomplished by the Bureau without funding support from the other agencies. Historically, the Hydrology Division has demonstrated competence and responsibility that has attracted such funding. With each progressive biennium, however, these funds become more scarce. A main objective, therefore, during the 1993 biennium will be to secure additional General Fund support that unquestionably will be needed to maintain some of the more important programs, particularly those in environmental hydrogeology including pesticides, agrichemicals and organic chemicals in groundwater, and expanded State support for the Bureau's vital Groundwater Information Center data bases on Montana water wells and groundwater.

In support of the operating geology and hydrology divisions, the Bureau will acquire Geographic Information System capabilities in the 1993 Biennium, and will continue the present Memorandum of Understanding with the State Library System to provide current digital geologic and hydrologic data to the State GIS user community. In anticipation of GIS needs, the Bureau has modernized and expanded its computer capabilities during the 1991 Biennium, and recognizes the absolute necessity for supplying both geologic and hydrologic data in digital form and as currently as possible to GIS users throughout the State. The Bureau expects to add Global Positioning System capabilities to its Geographic Information System as soon as possible, and hopefully by the time that GPS satellite coverage is completed in about two years. GPS capabilities are essential to virtually all Bureau field operations, because data acquired without locations are potentially misleading. The most accurate locations possible are needed, and GPS capabilities will meet that need.

Finally, the Bureau will continue efforts to modernize the Analytical Laboratory and will continue to modernize the Bureau Publications Office through applications of state-of-the-art computer technology. The Analytical Laboratory consistently ranks in the top 10 percent of similar water chemistry laboratories nation-wide, but needs major renovation of both analytical equipment and facilities. The Bureau has made major changes in the laboratory in the 1991 Biennium, but does not have the necessary funds for purchases of essential laboratory instruments.

Funding is being sought in outside grants, and in a joint Program Modification Request with Montana Tech, to restore the Analytical Laboratory and expand its unique capabilities into a major Analytical Laboratory Center that will complement the functions of laboratories in other State agencies and the University System, and will provide a level of analytical support not available now in Montana.

ADMINISTRATIVE DIVISION

John Dunstan
Division Chief

The Administrative Division includes secretarial, clerical, administrative and accounting support personnel. The Division works closely with the College Business Office in providing general administrative support for processing travel documents, equipment purchasing, budget control, and for various personnel administrative tasks.

Financial Statement

	July 1, 1988-June 30, 1989	July 1, 1989-June 30, 1990
Revenue		
General Fund Appropriation	1,233,523	1,292,915*
Sales and Services	47,458	44,000
Total	$1,280,981	$1,336,915
Expenditures		
Personnel Services	859,258	948,710
Operating Expense		
Contracted services	114,206	102,000
Supplies and materials	29,729	23,730
Communications	32,220	34,000
Travel	62,243	67,000
Rent	21,772	25,000
Repair and maintenance	28,759	37,830
Miscellaneous expense	13,616	12,569
Total Operations	302,545	302,129
Equipment	59,178	26,076
Transfer	60,000	60,000
Total	$1,280,891	$1,336,915

Part-time student assistants

The Montana Bureau of Mines and Geology augments its staff through the employment of college students as part-time assistants. These students not only contribute to the research effort, but also gain experience in organized research as part of their academic training. During all or part of the 1988-1990 fiscal years, 55 students from the various departments were so employed.

*Includes $18,000.00 for the 1991 Biennium to continue the Poplar River monitoring project.

PUBLICATIONS DIVISION

H. L. James

Division Chief

Information Services

The Montana Bureau of Mines and Geology provides a variety of advisory, technical and information services related to the geological, mineral and ground-water resources of the State. These services are available to individuals, companies and governmental agencies. Staff members are available to respond to individual requests for information, whether by phone, mail or in person. Questions on all phases of geology, ground water and the mineral industry are welcomed. Rock and mineral specimens are identified upon request. Each inquiry received is regarded as an opportunity to inform the public and provide service to the State of Montana.

During the reporting period, records show that the Bureau received 5,353 visitors answered over 8,901 telephone calls and responded to 5,645 mail inquiries and requests.

Earth Science Information Center

In 1983, the Montana Bureau of Mines and Geology became an affiliate of the Earth Science Information Center (E.S.I.C.). This program is part of the information branch of the National Mapping Program administered by the U.S. Geological Survey its mission is to help users gain better, faster, low-cost access to the cartographic holdings of federal, State and private agencies.

Through microfiche indexing, catalogs and search systems, the Bureau can now assist interested persons and agencies in obtaining a variety of aerial and space imagery for the State of Montana. These coverages include Landsat imagery and the manned spacecraft photos from Apollo, Gemini and Skylab programs. The E.S.I.C. services are located in the publications sales office, Room 200, Main Hall.

Publications

In its role as a public geologic research organization, the Montana Bureau of Mines and Geology disseminates the results of its projects and programs through its own publication series. Consistent and reliable publications serve as a vehicle for the distribution of geologic data generated by Bureau staff members, by members of cooperating agencies, and by other scientists doing research on Montana's earth resources. Each year (in January) the Bureau issues a new price catalog (free upon request) of its publications. On a quarterly basis, the Bureau circulates over 350 announcement cards to interested persons, companies and agencies on current published items. This service is also free upon request.

Publications of the Bureau are made available at nominal prices designed to recover printing, duplication and postage costs. In addition, the Bureau participates in a worldwide exchange program that distributes over 300 copies of each publication to libraries and other state surveys. The Bureau also serves as an agent for the U.S. Geological Survey in the sale of geologic and topographic maps of Montana. Distribution of maps and publications is handled through the sales office, which is located in Room 200, Main Hall, on the campus of Montana College of Mineral Science and Technology in Butte. Publications are also available in the Billings office, located in Room 321, Petro Hall, on the campus of Eastern Montana College.

The budget for printing (contracted services)is appropriated at $74,000. Total publication sales for the reporting period amounted to $91,194.

Bureau publications are issued in eight categories, with the information contained therein classified as follows:

Memoirs (M)--Detailed, scientific study of a specific subject on earth science.

Bulletins (B)--Data sources, catalogs, bibliographies, indexes, directories, categorized studies and information.

Special Publications (SP)--Compilation of various works guidebooks, proceedings volumes, multiple authorships may include layman subjects.

Geologic Map Series (GM)--Mapped areas and presentations on various geologic themes may include some descriptive text or expanded explanations charts, tables, analytical data, etc.

Hydrogeologic Map Series (HM)--Mapped areas and presentations on various hydrogeologic themes may include some descriptive text or expanded explanations charts, tables, analytical data, etc.

Montana Atlas Series (MA)--Separate (full color) $1^{o}x2^{o}$ quadrangle sheets on a topographic base depicting geology, ground water, mineral resources and other subjects (when applicable).

Information Pamphlet Series (IP)--Generalized discussions of variable subject matter on earth science and general interest topics of Montana geology.

Reprint Series (R)--Reissue of previously out-of-print publications. Not limited to MBMG works.

During the reporting period, the Montana Bureau of Mines and Geology issued 17 new titles. In addition, 30 titles were placed on open file, and one publication was issued as a second printing (revised).

New Publications

Memoirs

M 61--Barite in Montana, Richard B. Berg, 1988, 100 p., 72 figs., 7 tables, 1 sheet.

M 62--Hydrogeologic responses: Twenty years of surface coal mining in southeastern Montana, Wayne A. Van Voast and Jon C. Reiten, 1988, 30 p., 17 figs., 2 appendices, 2 sheets.

Bulletins

B 128--Directory of Montana mining enterprises for 1988, compiled by Robin McCulloch, with a section on Gold placers: A signature for lode-gold deposits in Montana, 1989, 49 p., 6 figs., 1 table, 1 appendix, 1 sheet.

Special Publications

SP 92--The Stillwater Complex, Montana: Geology and guide, Gerald K. Czamanske and Michael L. Zientek (eds.), 1985, (2nd edition, revised), 396 p. 361 figs., 28 tables, 4 sheets. Prepared in cooperation with the U.S. Geological Survey.

SP 96--Precambrian and Mesozoic plate margins: Montana, Idaho and Wyoming, with field guides for the 8th International Conference on Basement Tectonics, Sharon E. Lewis and Richard B. Berg (eds.), 1988, 195 p., 103 figs., 18 tables.

Geologic Map Series

GM 47--Geologic map of the Ramsay quadrangle, Montana, Pamela Dunlap Derkey and Mervin J. Bartholomew, 1988. Scale 1:24,000.

GM 48--Coal resources of the Baker and Wibaux 30 x 60-minute quadrangles, eastern Montana and adjacent North Dakota, Mark A. Sholes, 1988, 5 sheets with 6-page pamphlet text. Prepared in cooperation with the U.S. Geological Survey. Scale 1:100,000.

GM 49--Coal stratigraphy and correlation in the Glendive 30 x 60-minute quadrangle, eastern Montana and adjacent North Dakota, Mark A. Sholes, Susan M. Vuke-Foster and Pamela Dunlap Derkey, 1989, 4 sheets with 9-page pamphlet text. Prepared in cooperation with the U.S. Geological Survey. Scale 1:100,000.

GM 50-A--Coal stratigraphy and correlation in the Sidney 30 x 60-minute quadrangle, eastern Montana and adjacent North Dakota (index map, cross sections, and fence diagram), J. E. Mathews, 1989, 4 sheets with 8-page pamphlet text, J. E. Mathews and E. M. Wilde. Prepared in cooperation with the U.S. Geological Survey. Scale 1:100,000.

GM 50-B--Coal stratigraphy and correlation in the Sidney 30 x 60-minute quadrangle, eastern Montana and adjacent North Dakota (coal and clinker outcrop, structure contour, coal isopach and interburden isopach maps of the Prittegurl, Pust, Elviro, and Sears intervals), J. E. Mathews, 1989, 4 sheets with 8-page pamphlet text, J. E. Mathews and E. M. Wilde. Prepared in cooperation with the U.S. Geological Survey. Scale 1:100,000.

GM 50-C--Coal stratigraphy and correlation in the Sidney 30 x 60-minute quadrangle, eastern Montana and adjacent North Dakota (coal and clinker outcrop, structure contour, coal isopach, and interburden isopach maps of the Budka, Lane, and Carroll intervals, J. E. Mathews, 1989, 3 sheets with 9-page pamphlet text, J. E. Mathews and E. M. Wilde. Prepared in cooperation with the U.S. Geological Survey. Scale 1:100,000.

GM 50-D--Coal stratigraphy and correlation in the Sidney 30 x 60-minute quadrangle, eastern Montana and adjacent North Dakota (Paleogeographic diagrams of the Prittegurl, Pust, Elviro, Sears, Budka, and Lane intervals), J. E. Mathews, 1989, 1 sheet with 8-page pamphlet text, J. E. Mathews and E. M. Wilde. Prepared in cooperation with the U.S. Geological Survey. Scale 1:100,000.

GM 51--Geologic map of the Dickie Peak quadrangle, Deer Lodge and Silver Bow Counties, Montana, Sharon E. Lewis, 1990. Scale 1:24,000.

Hydrogeologic Map Series

HM 8--Water resources of the Clarks Fork Yellowstone River valley, Montana, Julianne F. Levings, 1986, 5 tables, 3 sheets. Prepared in cooperation with the U.S. Geological Survey. Scale 1:25,000.

HM 9-A--Hydrogeologic map of the Billings 1° x 2° quadrangle and vicinity, Montana: Cambrian through Permian rocks, R. D. Feltis, 1988. Prepared in cooperation with the U.S. Geological Survey. Scale 1:250,000.

HM 9-B--Hydrogeologic map of the Billings 1° x 2° quadrangle and vicinity, Montana: Jurassic rocks (Ellis Group and Morrison Formation),

R. D. Feltis, 1988. Prepared in cooperation with the U.S. Geological Survey. Scale 1:250,000.

HM 9-C--Hydrogeologic map of the Billings $1^{\circ} \times 2^{\circ}$ quadrangle and vicinity, Montana: Lower Cretaceous rocks (Lakota Formation), R. D. Feltis, 1988. Prepared in cooperation with the U.S. Geological Survey. Scale 1:250,000.

HM 9-D--Hydrogeologic map of the Billings $1^{\circ} \times 2^{\circ}$ quadrangle and vicinity, Montana: Lower and Upper Cretaceous rocks (Dakota sandstone through Telegraph Creek Formation), R. D. Feltis, 1988. Prepared in cooperation with the U.S. Geological Survey. Scale 1:250,000.

HM 9-E--Hydrogeologic map of the Billings $1^{\circ} \times 2^{\circ}$ quadrangle and vicinity, Montana: Upper Cretaceous rocks (Eagle sandstone through Bearpaw Shale), R. D. Feltis, 1988. Prepared in cooperation with the U.S. Geological Survey. Scale 1:250,000.

HM 9-F--Hydrogeologic map of the Billings $1^{\circ} \times 2^{\circ}$ quadrangle and vicinity, Montana: Upper Cretaceous rocks (Lennup Sandstone through Quaternary rocks), R. D. Feltis, 1988. Prepared in cooperation with the U.S. Geological Survey. Scale 1:250,000.

<u>Information Pamphlet Series</u>

IP 1--Butte-Under the hill: A brief introduction to mining and geology, Sharon E. Lewis, 1989, 9 p., 6 figs.

Open-File Reports

In addition to new titles, the Bureau also maintains an extensive open file on various geologic projects. The open-file reports and maps are a means by which information is made available to the public on investigations that are preliminary in content, awaiting publication, or for various reasons are unpublished. These materials may be examined and studied at the Butte office. Photocopies can be purchased by mail or in person. New titles placed on open file during the biennium are as follows:

MBMG 201--Preliminary geologic map of plutonic units of the Boulder batholith, southwestern Montana, Harry W. Smedes, Montis R. Klepper and Robert I. Tilling, 1988. Prepared in cooperation with the U.S. Geological Survey (USGS Open-File Report 88-283). Scale 1:200.000.

MBMG 202--Final Report: Agricultural Chemical Hydrogeology Program, Jon Reiten, Joseph J. Donovan, Thomas W. Patton and Marvin R. Miller, 1988, 48 p., 7 figs., 3 appendices.

MBMG 203--Biennial report of activities and programs of the Montana Bureau of Mines and Geology - July 1, 1986-June 30, 1988, compiled by Edward T. Ruppel, 1988, 229 p., 52 figs., 4 tables.

MBMG 204--Montana seismicity report for 1986, Michael C. Stickney, 1988, 39 p., 8 figs., 7 tables.

MBMG 205--Hydrogeologic analysis of septic system nutrient attenuation efficiencies in the Evergreen area, Montana, Jon Buckalew King, 1988, 81 p., 12 figs., 1 table, 4 appendices.

MBMG 206--Mining and mineral developments in Montana - 1988, Robin McCulloch, 1988, 19 p., 7 fig., 1 table.

MBMG 207--Mine and mineral occurrence database for Madison County, Montana, Robert E. Derkey and Pamela Dunlap Derkey, 1988, 536 p., 1 sheet.

MBMG 208--Ground-water and geologic data for northeastern Montana in the Wolf Point 1^{o}x 2^{o}quadrangle, Joseph J. Donovan, 1988, 633 p.

MBMG 209--Ground-water geology and high-yield aquifers of northeastern Montana, Joseph J. Donovan, 1988, 116 p., 34 figs., 10 tables, 1 appendix, 3 sheets.

MBMG 210--Arsenic contamination of aquifers caused by irrigation with diluted geothermal water in the lower Madison valley, Montana, John L.

Sonderegger, Brenda R. Sholes and Takeshi Ohguchi, 1989, 23 p., 2 figs., 2 tables, 1 appendix.

MBMG 211--Hydrogeological reconnaissance of abandoned underground coal mines near Roundup, Montana, Jon C. Reiten and John R. Wheaton, 1989, 100 p., 9 figs., 4 tables, 4 appendices, 3 sheets.

MBMG 212--Reconnaissance geologic maps of the northeastern part of the Belt 30 x 60-minute quadrangle, west-central Montana, Susan M. Vuke-Foster, Richard B. Berg and Roger B. Colton, 1989. Scale 1:24,000.

MBMG 213--Reconnaissance geologic maps of the northeastern part of the Belt 30 x 60-minute quadrangle, west-central Montana, Susan M. Vuke-Foster and Roger B. Colton, 1989. Scale 1:24,000.

MBMG 214--Removal of heavy-metal ions from mine tailings-impacted ground water through contact with natural zeolites, Theodore S. Jordan, Terence E. Duaime and Christopher J. Hawe, 1988 (1989), 47 p., 4 figs., 11 tables, 3 appendices.

MBMG 215--Reclamation techniques for heavy-metal contaminated agricultural lands in Deer Lodge, Powell and Silver Bow counties, Montana, John Sonderegger and Wallace Wilson, 1989, 18 p., 8 figs., 4 tables.

MBMG 216--Current geological and geophysical studies in Montana, compiled by Richard B. Berg, 1989, 43 p., 2 figs.

MBMG 217--Montana's industrial minerals, Richard B. Berg, 1989, 39 p., 1 fig.

MBMG 218--Final report: Travona mine aquifer test - summary water-quality monitoring, sampling and results, Silver Bow County, Montana, Terence E. Duaime, Richard A. Appleman, Marvin R. Miller and John L. Sonderegger, 1989, 114 p., 80 figs., 18 tables, 4 appendices.

MBMG 219--Final report: Travona mine aquifer test - water-level observations and aquifer characteristic interpretation, Silver Bow County, Montana, John J. Metesh, Terence E. Duaime and John L. Sonderegger, 1989, 112 p., 27 figs., 3 tables, 5 appendices.

MBMG 220--Map of dissolved solids in the Judith River Formation and equivalent rocks, Thomas W. Patton, Robert N. Bergantino, Brenda C. Sholes and Joan B. Alexander, 1989. Scale 1:1,000,000.

MBMG 221--Map of dissolved solids in the Kootenai Formation and equivalent rocks, Thomas W. Patton, Robert N. Bergantino, Brenda C. Sholes, and Joan B. Alexander, 1989. Scale 1:1,000,000.

MBMG 222--Montana seismicity for 1987, Michael C. Stickney, 1989, 43 p. 8 figs., 7 tables.

MBMG 223--Mining and mineral developments in Montana for 1989, Robin McCulloch, 1989, 42 p., 12 figs., 1 table.

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MBMG 225-A--Preliminary geologic map of the Deerlodge National Forest, Montana (western part), 1990: U.S. Forest Service. Scale 1:126,720.

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MBMG 226--Poplar River monitoring, Fred A. Schmidt and Brenda C. Sholes, 1990, 170 p., 4 figs., 3 tables, 2 appendices.

MBMG 227--Hydrogeology of the Colorado tailings, Terence E. Duaime, Robert N. Bergantino and Herman R. Moore, 1990, 159 p., 17 figs., 10 tables, 6 appendices. Prepared in cooperation with the Montana Department of State Lands.

MBMG 228--Upper Clark Fork River basin storm-event monitoring, Terence E. Duaime and Richard A. Appleman, 1990, 162 p., 59 figs., 28 tables, 8 appendices. Prepared in cooperation with the Montana Department of Health and Environmental Sciences.

MBMG 229--Reconnaissance geologic map of the Grass Range-Winnett area, central Montana, Karen Porter, 1990, 1 sheet with 15-page pamphlet text. Prepared in cooperation with the U.S. Geological Survey. Scale 1:100,000.

Outside Publications

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GEOLOGY AND MINERAL RESOURCES DIVISION

Mervin J. Bartholomew
Division Chief

The Geology and Mineral Resources Division provides information in the form of maps and reports on the State's mineral and energy resources, geologic hazards and geology, and provides assistance to the State's mineral industries. The Division's budget, exclusive of the Earthquake Studies Office, was $276,939 and $273,869 for FY89 and FY90 from State appropriated funds. The Earthquake Studies Office received $20,834 (FY89) and $20,453 (FY90) from State funds. In FY89 and FY90 the Division also received $74,179 and $81,555 in outside contracts and grants primarily from agencies of the federal government. The principal accomplishments of the Division were: publication of a Memoir on Barite in Montana; publication of three reports on the Coal Resources of four 30x60-minute quadrangles in eastern Montana; publication of a Special Paper on Precambrian and Mesozoic Plate Margins, Montana, Idaho and Wyoming, which was done in conjunction with the 8th International Conference on Basement Tectonics; publication of two 7.5-minute quadrangles in western Montana; and publication of numerous short papers, pamphlets, open-file reports, yearly catalogues and reports, and abstracts pertaining to the geology and mineral resources of Montana.

Goals and Objectives

The long-range goals and objectives for the GMR Division are contained in the Bureau's long-range plan for the period FY87 to FY92. The programs are designed to take maximum advantage of supplemental contracts and grants to complete specific projects with the present staff and financial resources of the Division.

The Division has 6.62 professional and 1.0 classified positions funded from State appropriations and 1.0 professional positions funded by contracts and grants. During FY89/90 the Division staff responded to hundreds of inquiries from the scientific community, the mineral industries, Federal and State agencies, the news media and the general public in Montana and elsewhere in the United States and foreign countries. During FY89/90 the Division staff have completed 37 investigations for publication or open-file and are currently working on 26 investigations in addition to ongoing investigations.

The major programs of the Geology and Mineral Resources Division are:

1) **Geologic Framework Program** is designed to provide a skeletal framework of geologic data in key regions that can be extrapolated throughout the State for an overview of the geology of Montana. The principal investigations under this program are projects related to the State Geologic Map, to key transects, and to Natural Hazards Investigations. Special projects also are included within this program. The status of geologic mapping on modern topographic base maps in Montana is shown on Figures 1-4 for different scales of quadrangle maps.

2) **Mineral Resources Program** consists of projects that provide information and assistance on the State's mineral and energy resources. Where possible, the work is coordinated with the Geologic Framework Program so that geologic data are available when resource investigations are initiated.

3) **Educational Program** plays a subordinate but important role in the Division's efforts to disseminate geologic and mineral resource information to the general public.

Projects of the Geologic Framework Program

State Map Project

The principal 7-year project is an effort to complete and publish an up-to-date geologic map of the State at a scale of 1:500,000. The project, which was initiated in the last biennium, is a cooperative venture with the U.S. Geological Survey. During FY89/90, the USGS provided $100,000 under the COGEOMAP Program to the MBMG, with matching fund commitments by the MBMG. The Geology and Mineral Resources Division has the primary responsibility for completing the Great Plains portion (twelve 1^{o}x 2^{o} quadrangles) of the map (Figure 5) as well as contributing to geologic mapping in selected areas in the western part of the state. The State Map Project utilizes both work previously done under the Montana Atlas project and current work in eastern

1 X 2 DEGREE SERIES
1:250 000 SCALE

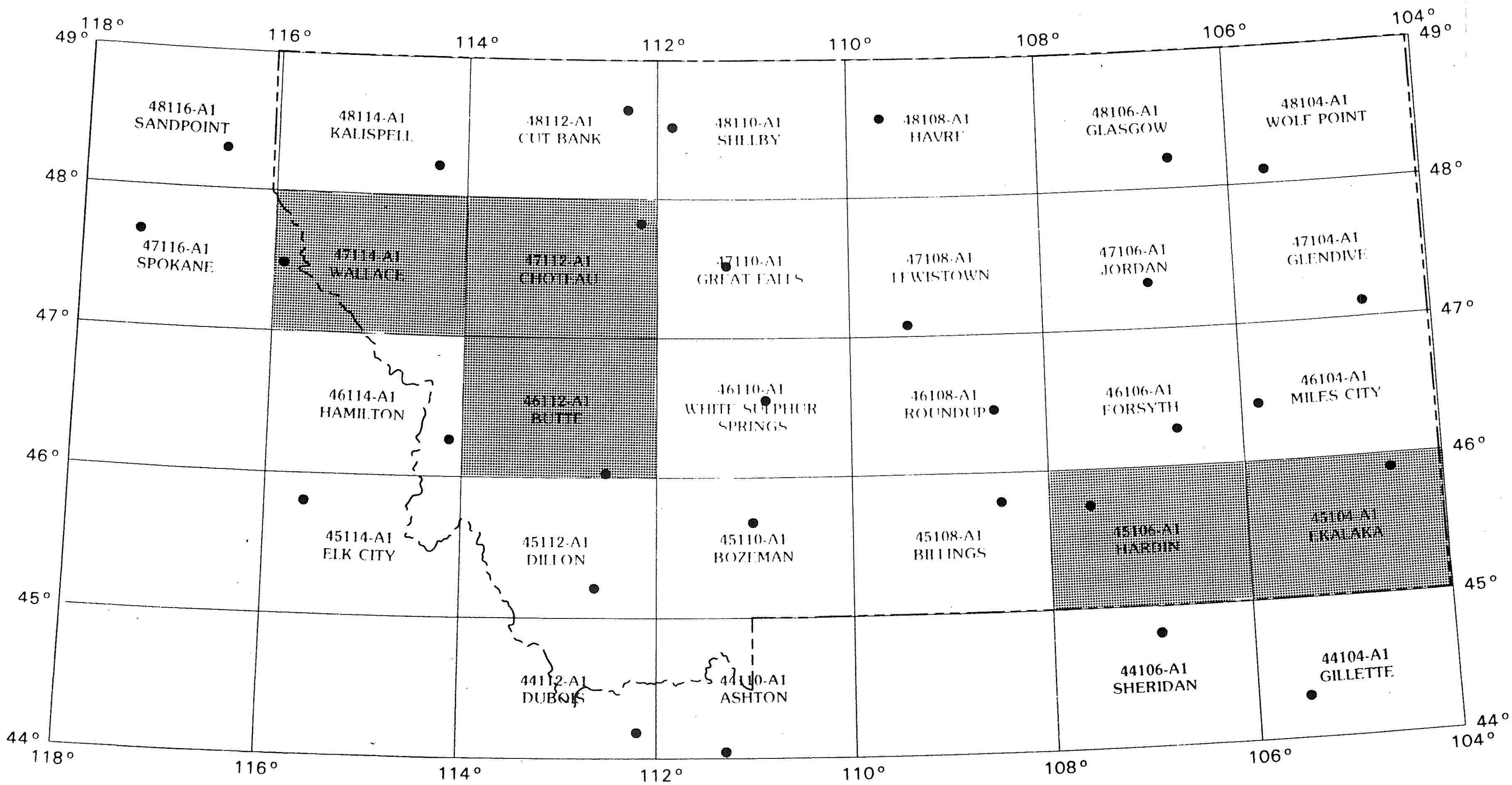

Figure 1 — Map showing published (shaded) 1 x 2-degree quadrangles in Montana.

30 X 60 MINUTE SERIES
1:100 000 SCALE

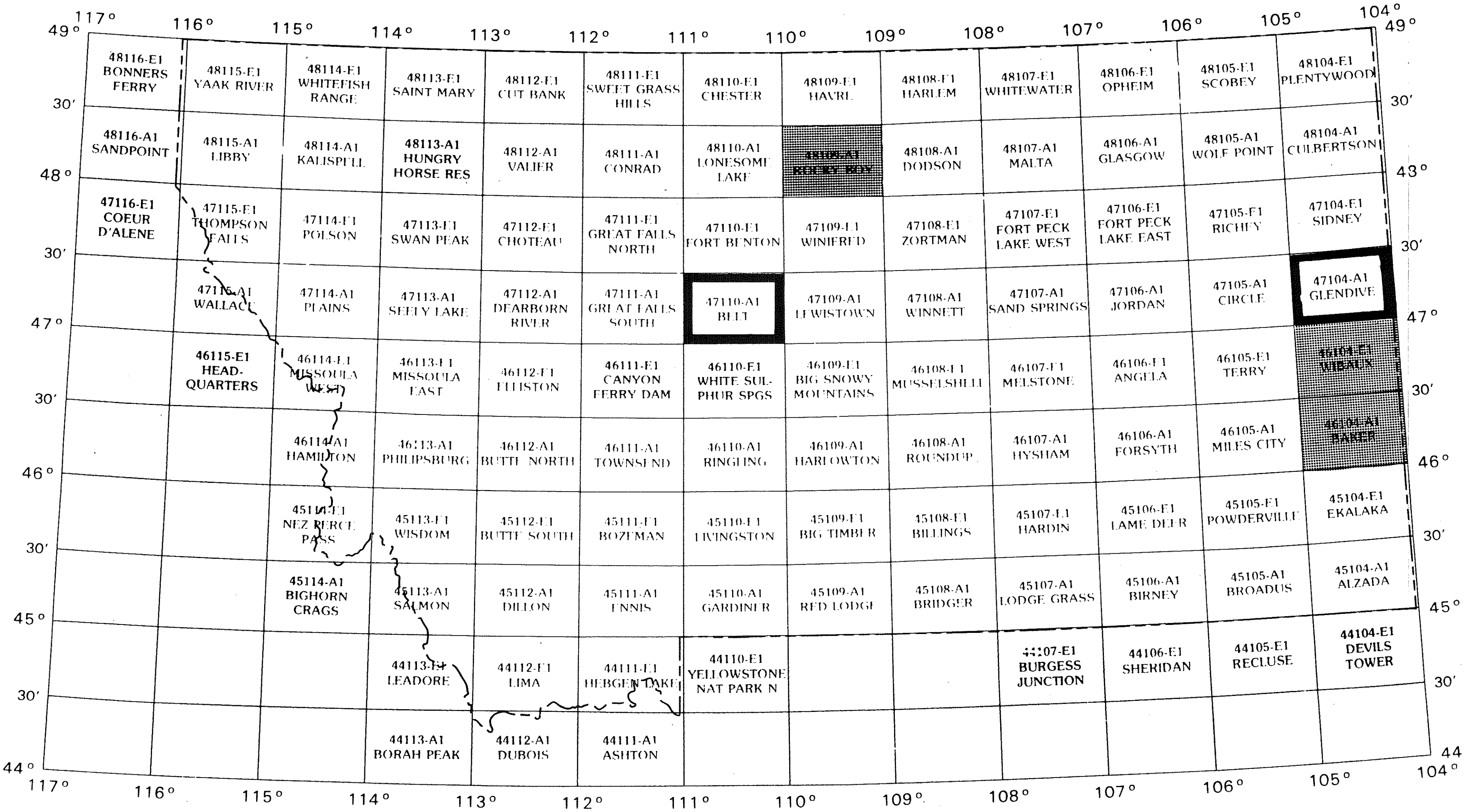

Figure 2 — Map showing published (shaded) and completed (open) 30 x 60-minute quadrangles in Montana.

15 MINUTE SERIES

1:50,000 SCALE

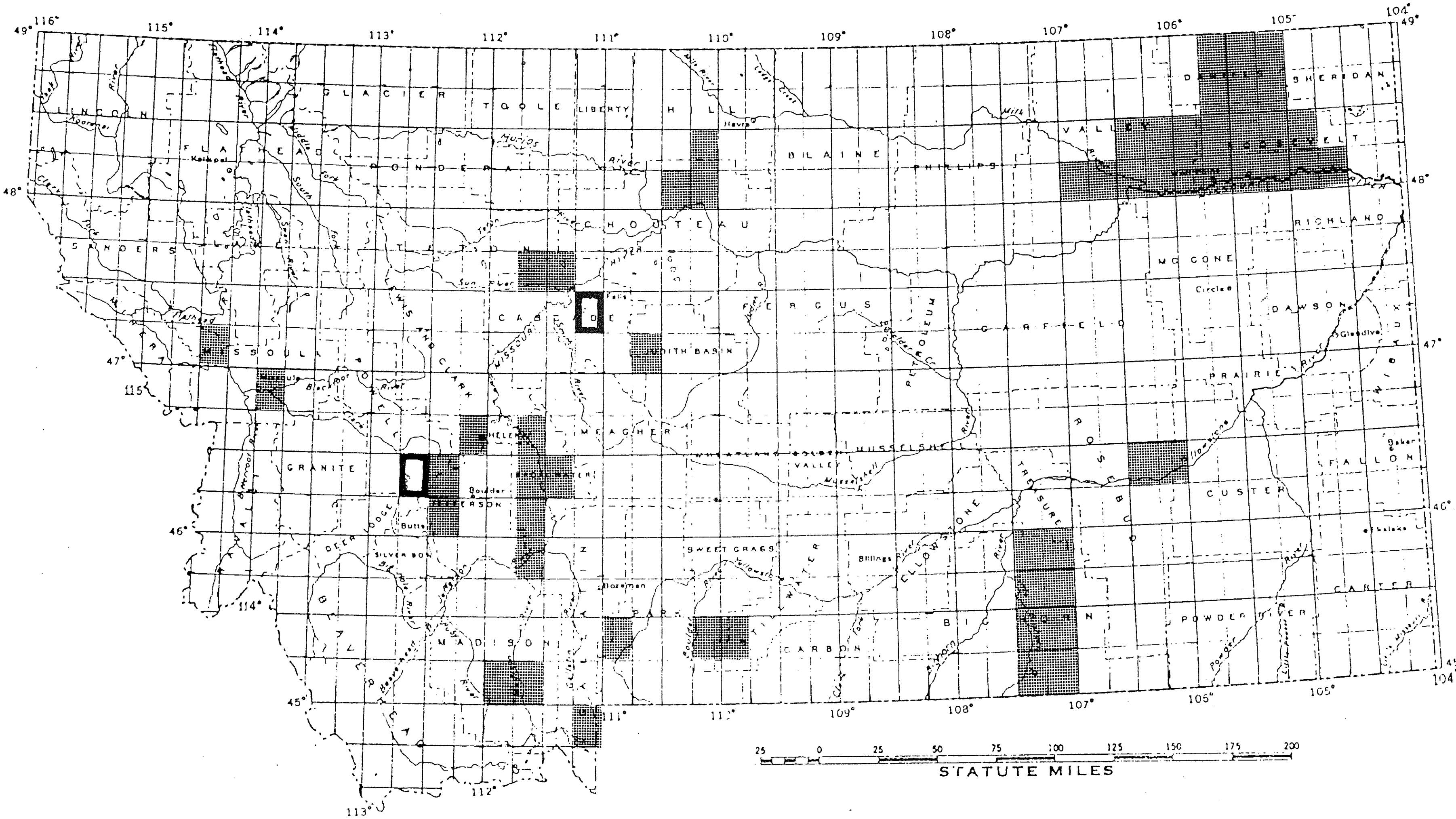

Figure 3 — Map showing published (shaded) and completed (open) 15-minute quadrangles in Montana.

7½ MINUTE SERIES
1:24,000 SCALE

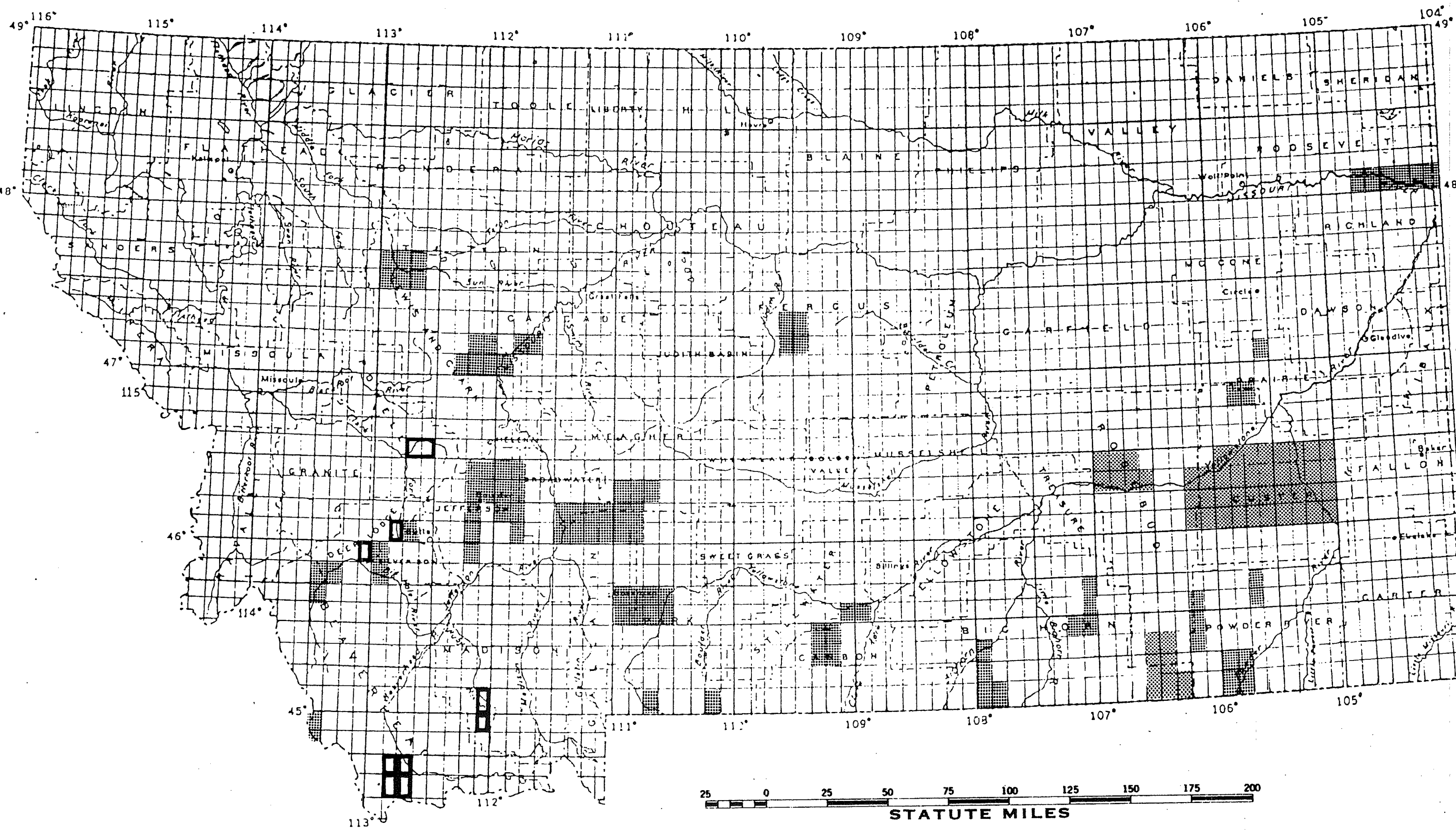

Figure 4—Map showing published (shaded) and currently being mapped (open) 7½-minute quadrangles in Montana.

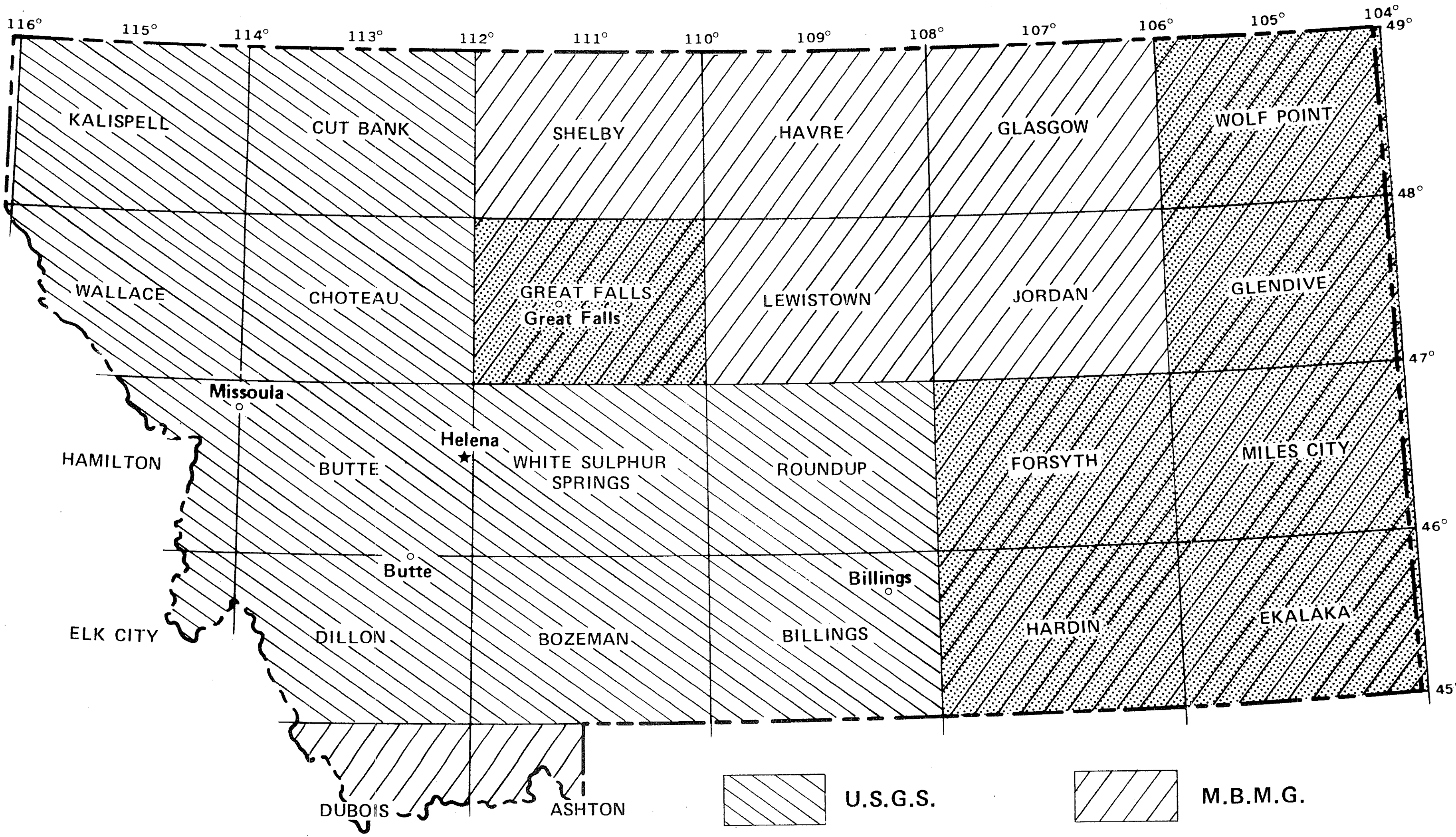

Figure 5 — Map of Montana showing areas of responsibility for USGS and MBMG; shaded 1 x 2-degree quadrangles are those that are completed (Hardin, Ekalaka, Miles City, Forsyth) or are currently being compiled by MBMG staff (Great Falls, Glendive, Wolf Point).

Montana, and includes compilation of published mapping and additional reconnaissance mapping. During FY89/90 compilation of the Ekalaka, Miles City, Hardin and Forsyth 1^{o}x 2^{o} quadrangle areas were completed, and late in FY90 work was begun on the Glendive, Wolf Point and Great Falls 1^{o}x 2^{o} quadrangles.

Great Plains Transects

The Great Plains transects are an integral part of the State Map Project and are the regions in which the Division staff concentrates mapping efforts to produce publishable maps at 1:100,000 scale (Figure 6). The transects provide more detailed geologic maps across the Great Plains. The Alzada-Plentywood transect is about one third completed and about one half of the Great Falls-Glendive transect is currently being mapped.

The Alzada-Plentywood Transect

In the Alzada-Plentywood north-south transect the geology of the Baker, Wibaux and Glendive quadrangles and part of the Sidney quadrangle were mapped in cooperation with the U.S. Geological Survey in the Coal Lands Mapping Project (1982 to 1986).

The area in easternmost Montana covered by these maps contains extensive coal deposits and the Cedar Creek anticline and the Williston basin which are major oil-producing structures. The Cedar Creek anticline is currently Montana's leading oil-producing area, contributing more than 8 billion barrels of oil per year and significant amounts of natural gas. Geologic mapping of both the anticline and the basin provides both oil and coal companies with information on the surface geology that complements extensive subsurface data.

A geologic map of the Baker and Wibaux quadrangles was published during the last biennium. The geologic map of the Glendive quadrangle was completed, partly reviewed and is being revised for publication by MBMG in FY91. The Geologic map of the Sidney quadrangle is nearing completion.

Great Falls-Glendive Transect

This east-west transect shares the Glendive quadrangle with the Alzada-Plentywood transect discussed above. During the FY89/90 biennium staff geologists have been mapping the western part of the transect; the Great

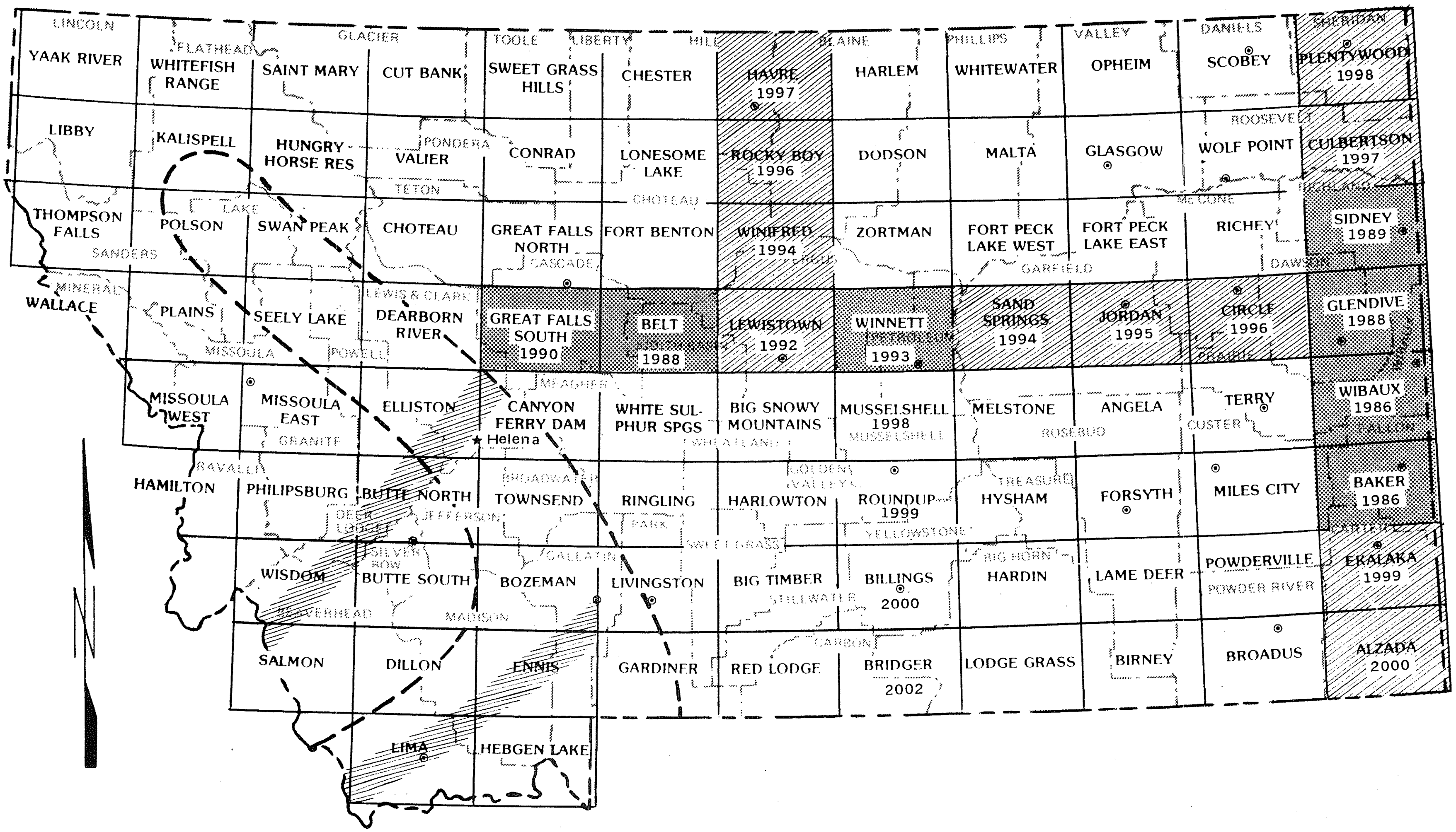

Figure 6 — Map of Montana showing Great Plains transects of 30 x 60-minute quadrangles; shaded quadrangles are published (Baker, Wibaux) or currently being mapped (Glendive, Sidney, Winnett, Belt, Great Falls S.) by MBMG staff.

Map also shows two Rocky Mountain transects relative to area of high earthquake hazard.

Falls, Belt, and Winnett quadrangles. Mapping of the Belt quadrangle began in the last biennium as part of another COGEOMAP contract ($5,000) to Richard B. Berg and Susan M. Vuke-Foster. The field sheets have been open-filed (Vuke-Foster and others, 1989a; Vuke-Foster and Colton, 1989) and the Belt geologic map was completed during FY89 and is being prepared for review during FY91. Preliminary results of this work were presented at the Rocky Mountain section meeting of the Geological Society of America (Vuke-Foster and others, 1989b). The Belt sheet will be published at a scale of 1:100,000 during FY92.

Two 7 1/2-minute quadrangles (Monarch and Thunder Mountain) in the Belt quadrangle, were mapped in detail and open-filed during the last biennium. Work in the Winnett quadrangle was started in FY90 and a preliminary map of the southern half of the quadrangle has been completed and open-filed (Porter, 1990).

Geologic studies in the northeast part of the Great Falls quadrangle has been carried out intermittently from 1983 to the present. Geologic mapping was initiated in conjunction with a hydrologic study of the acid mine-water discharge from abandoned coal mines in the Stockett and Sand Coulee areas, and preliminary geologic maps of the Stockett and Great Falls South 7 1/2-minute quadrangles were open-filed last biennium. Because of renewed industry interest in the Great Falls coal field, detailed mapping of six 7 1/2-minute quadrangles in the region between the towns of Stockett and Belt was completed during FY90. The final product will be a geologic map (1:50,000 scale) showing the surface and subsurface (where known) extent of the coal-bearing strata as well as other units.

Rocky Mountain Transects

These transects are designed to provide geologic maps of important areas in the mountainous western portion of the State. The Lima-Bozeman transect (Figure 6) is in the most seismically active part of Montana and has been the site of extensive recent petroleum exploration. The Wisdom-Wolf Creek transect (Figure 6) also crosses the northern part of the seismically active zone, and crosses part of the mineralized volcanic and plutonic rocks that have yielded significant precious metal deposits and have a high potential for new precious metals discoveries.

Lima-Bozeman Transect

The transect (Figure 7) extends westward from Bozeman to the state boundary west of Lima. It includes thirty-six 7 1/2-minute quadrangles, nine have been partly or completely mapped by MBMG or USGS geologists. West of Lima the transect crosses the Cordilleran fold and thrust belt where detailed work on the Dell and Dixon Mountain quadrangles is in progress to determine the sequence of thrusting and the interaction of the foreland with the fold and thrust belt (Bartholomew, 1988b, 1989a, 1989b). The McKnight Canyon wildcat well was drilled just north of the Dixon Mountain quadrangle. Geological mapping of five 7 1/2-minute quadrangles is also in progress in the Snowcrest Range near the center of the transect where the Cornell Camp Federal 1-20 well was drilled in 1987. Publication of several 7 1/2-minute quadrangles is expected during the next biennium.

Wisdom-Wolf Creek Transect

The transect (Figure 8) extends from the western end of the Great Falls-Glendive transect westward across the geologically complex mountains of western Montana. The Wisdom-Wolf Creek transect contains forty-six 7 1/2-minute quadrangles. Twenty of these have been partly or completely mapped by MBMG and USGS geologists. In the Deer Lodge area four quadrangles (Deer Lodge, Baggs Creek, Dempsey, Sugarloaf Mountain) have been completed, reviewed, and are undergoing final revision for publication as a single map at 1:50,000-scale during FY91. Mapping is nearly completed in two adjacent quadrangles (Luke Mountain, Avon). The work in this region has been aimed at determining the stratigraphy, petrology and structure of the Cretaceous Elkhorn Mountain Volcanics which host the mineralization in the Emery district near Deer Lodge.

The Eocene Lowland Creek Volcanics host the mineralization around the Tuxedo mine in the Ramsay quadrangle which was published in FY89. Work is in progress in the adjacent Opportunity quadrangle (Derkey and Bartholomew, 1988). The Pegasus Corporation Beal Mountain mine is in the nearby Dickie Peak quadrangle (Lewis, 1990; Lewis and Bartholomew, 1989; Lewis and Fier, 1989). Geologic mapping of the adjacent Lincoln Gulch quadrangle will be completed in FY91. The mapping shows a complex series of deformed thrust plates, and presents a clearer understanding of the three-dimensional geological aspects of the region.

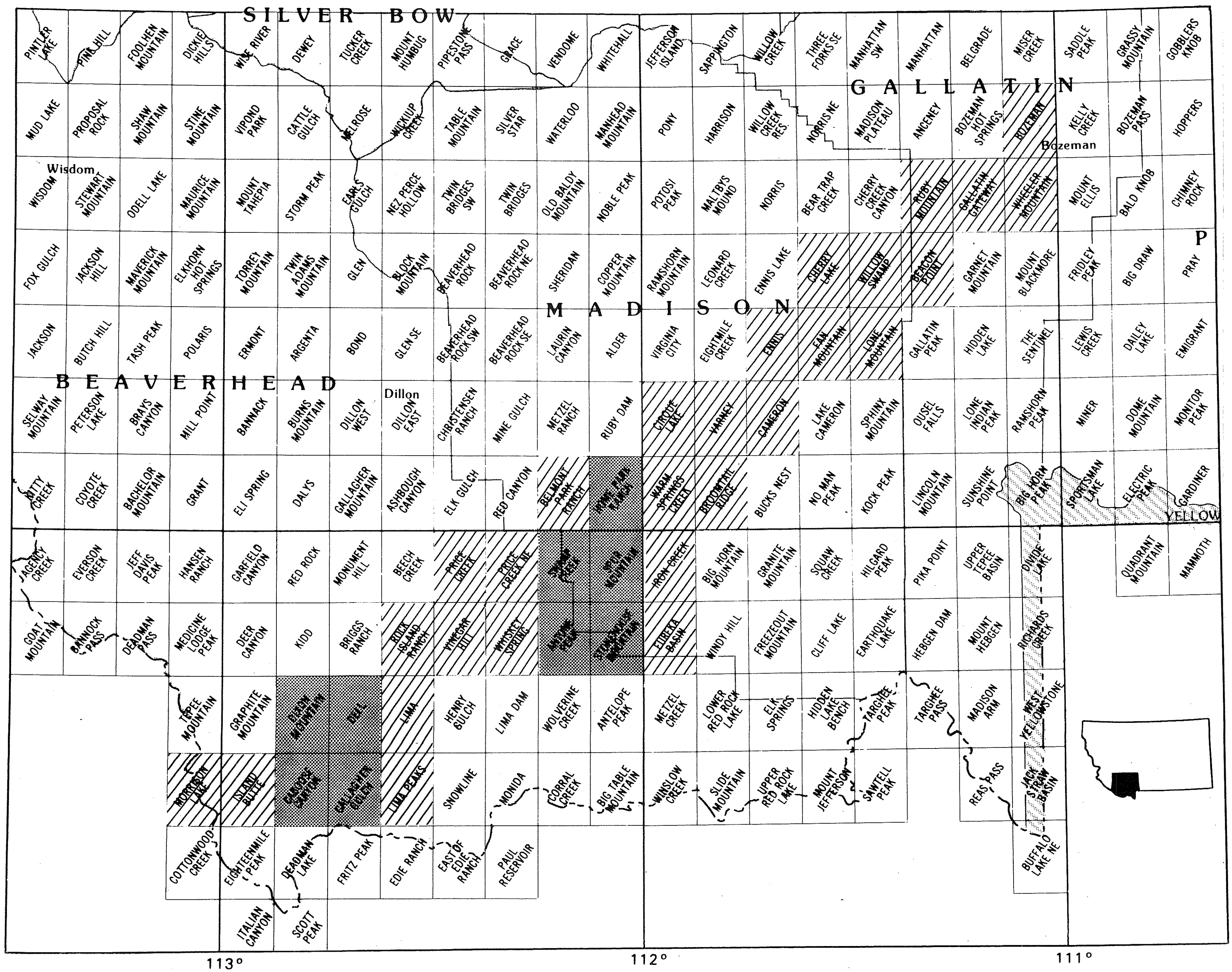

Figure 7 — Lima-Bozeman transect showing 7½-minute quadrangles currently being mapped.

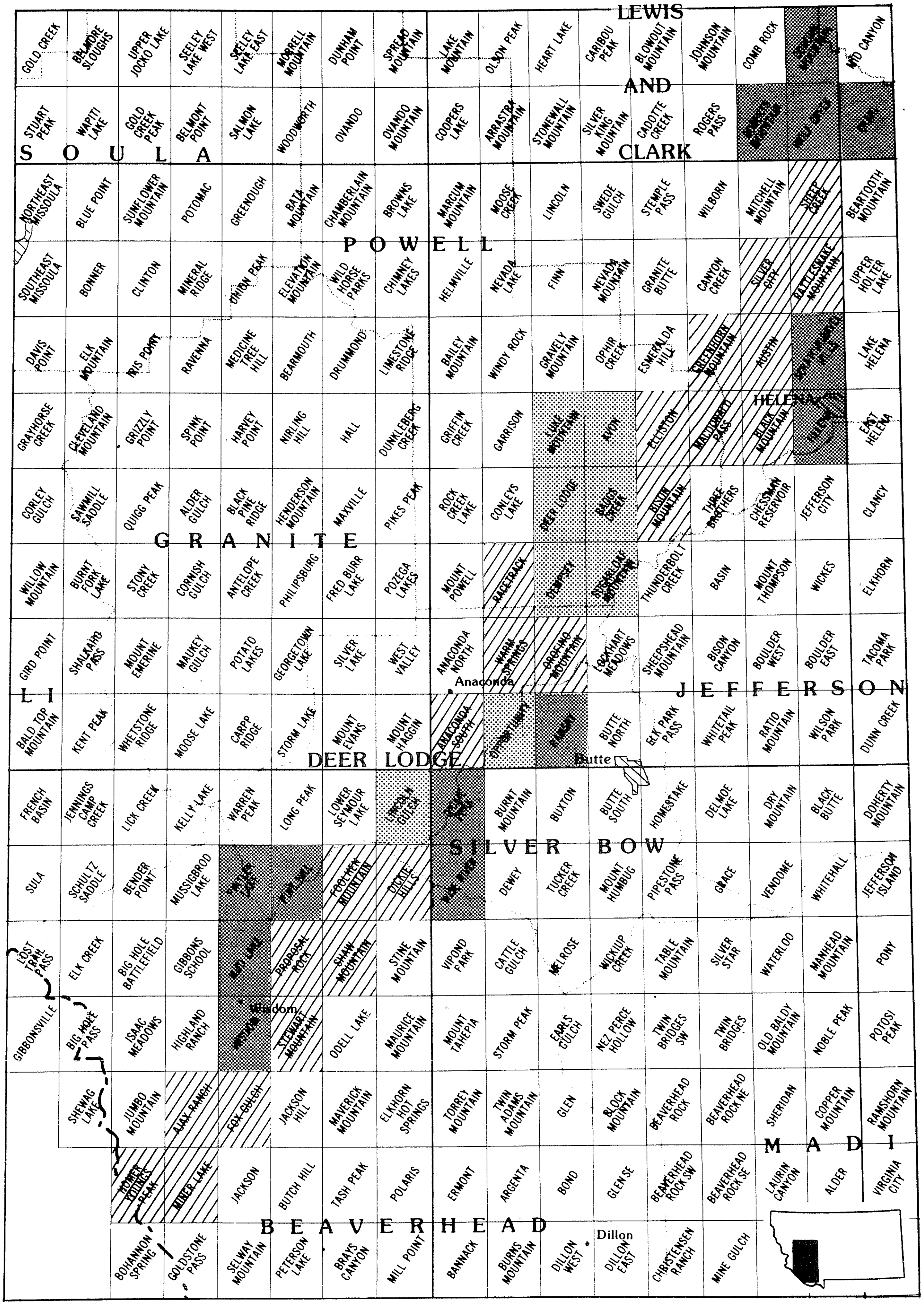

Figure 8 — Wisdom-Wolf Creek transect showing 7½-minute quadrangles that are published (dark shading) or currently being mapped (light shading) relative to gold/silver deposits.

Geologic Hazard Assessment Projects

Earthquake Studies Office

The seismic monitoring capabilities of the Earthquake Studies Office, under the direction of Michael C. Stickney, has grown from a single station seismograph in 1980 to a network of 10 stations providing coverage of about 5,700 square miles in southwestern Montana (Figure 9). Data from nine solar-powered, remote stations are continuously telemetered to the Earthquake Studies Office on the Montana Tech campus, using low-power FM radio links. The seismic data is recorded on slowly rotating, paper-covered drums along with timing marks from a precise clock. During FY89/90 the office obtained equipment to digitally record the signals from many of the remote stations. Each morning, the recording paper is changed and the seismograms (records written by the seismographs) are labeled and natural earthquakes in the region are identified. With the aid of a computer the office determines epicenters and depths below ground surface and origin time for local earthquakes. Once epicenter locations are determined, the data are included in an annual catalog of earthquake activity in Montana and adjacent parts of Idaho, Wyoming and Canada. The 1986 and 1987 catalogues (Stickney, 1988b; 1989b) contains 792 and 1025 earthquake locations, respectively.

Earthquake activity in Montana is concentrated along two principal zones, the intermountain seismic belt and the more active Centennial tectonic belt. Destructive earthquakes occurred along the Intermountain Seismic Belt in 1925 in the Clarkston valley just north of Three Forks (M = 6 3/4 $1.8 million damage) and in Helena during 1935. Helena was shaken by several thousand earthquakes in 1935-36, the two largest occurred on October 18 (M = 6 1/4, 2 killed, $19 million damage) and on October 31 (M = 6.0, 2 killed, $6 million damage). The sites of major historic earthquakes continue to experience minor earthquakes. The Centennial tectonic belt extends from the Hebgen Lake-Yellowstone Park area westward through southwestern Montana into east-central Idaho. It was the site of two destructive earthquakes during the past 29 years. The 1959 Hebgen Lake earthquake (magnitude = 7.5) caused $26 million in damage, triggered a massive landslide that dammed the Madison River and claimed 28 lives. The 1983 Borah Peak, Idaho earthquake claimed 2 lives and caused $15 million in damage.

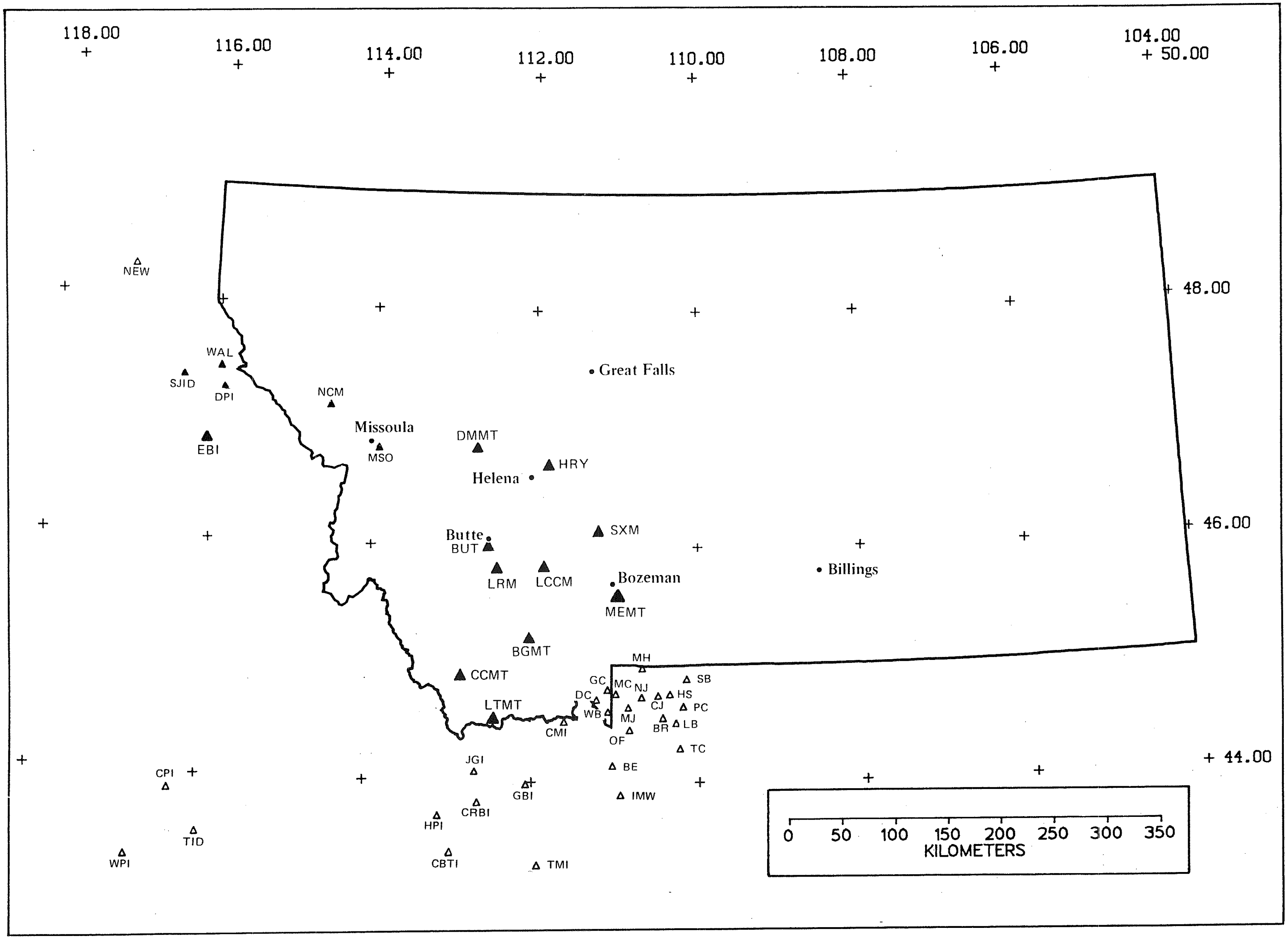

Figure 9 — Map of Montana showing existing (▲MBMG; △other agencies) seismic stations used for epicenter locations.

Currently, the Montana seismograph network contains 10 stations with an average interstation spacing of about 75 km. The existing network is capable of locating all earthquakes of magnitude 2.0 or greater within the network but the network does not surround either the Centennial tectonic belt or the intermountain seismic belt. The large interstation spacing and low number of stations in the network is such that reliable depths and fault-plane solutions can be determined only for the most favorably situated earthquakes.

The Earthquake Studies Office also has five portable seismograph stations used for monitoring earthquake aftershocks or swarms of earthquakes. During the FY89/90 biennium the Earthquake Studies Office responded to several hundred telephone inquiries, provided 108 written responses, and delivered about 25 oral presentations to professional groups, schools, civic groups and county emergency personnel (Stickney, 1989a, 1990).

Earthquake/Active Fault/Landslide Hazard Investigations

Earthquake data are combined with geologic mapping and trenching of active faults to assess active fault/earthquake hazards in Montana (Bartholomew, 1988a, 1989a; Stickney and Bartholomew, 1987; Bartholomew, Stickney and Wilde, 1990; Bartholomew and others, 1988). Active faults are those which are likely to experience surface rupture during major earthquakes similar to events at Hebgen Lake and Borah Peak. Twenty-two active faults have been identified in southwest Montana, and others are known in the Townsend basin, near Pipestone, and north of Whitehall (Bartholomew, 1988a; Stickney and Bartholomew, 1987) (Figure 10).

The greatest active fault/earthquake hazard (Figure 11) is in southwestern Montana in Beaverhead, Madison, Gallatin, and Park counties. Bozeman, Livingston, Dillon, and many smaller communities all lie in the region of greatest hazard. Silver Bow, Jefferson, Broadwater, Lewis and Clark, Powell, Lake, and Flathead counties are in the region of the next highest hazard. This region includes Butte, Helena, Kalispell, and many smaller communities. For the impact of geologic hazard to be assessed, each active fault must be mapped in sufficient detail to determine the length of fault segments that may slip independently of adjacent segments. Trenches dug perpendicular to fault scarps provide a visual record of how often an individual fault segment has ruptured the ground surface during major

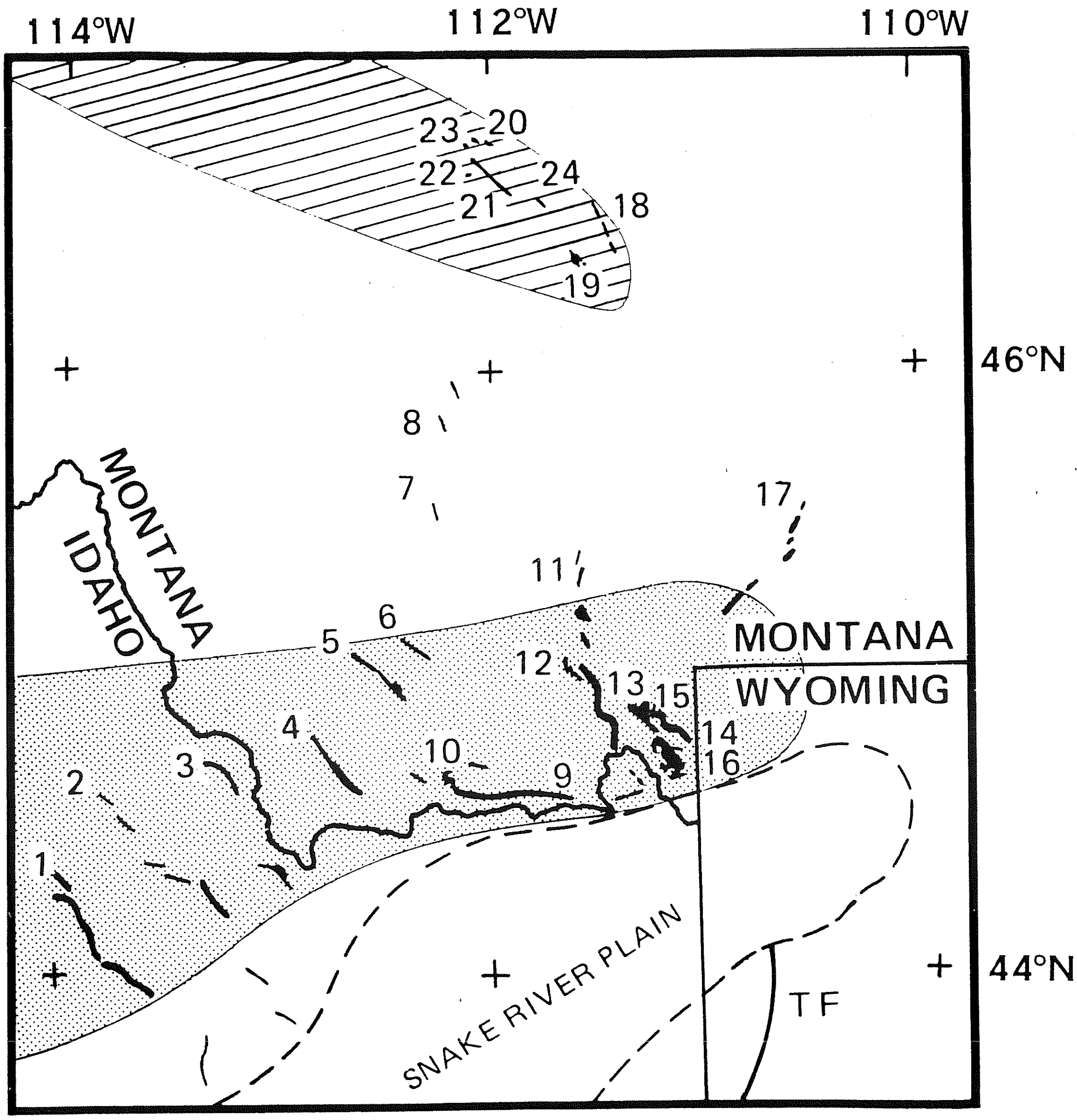

Figure 10 — Map showing distribution of active faults in southwestern Montana and adjacent areas (from Stickney and Bartholomew, 1987).

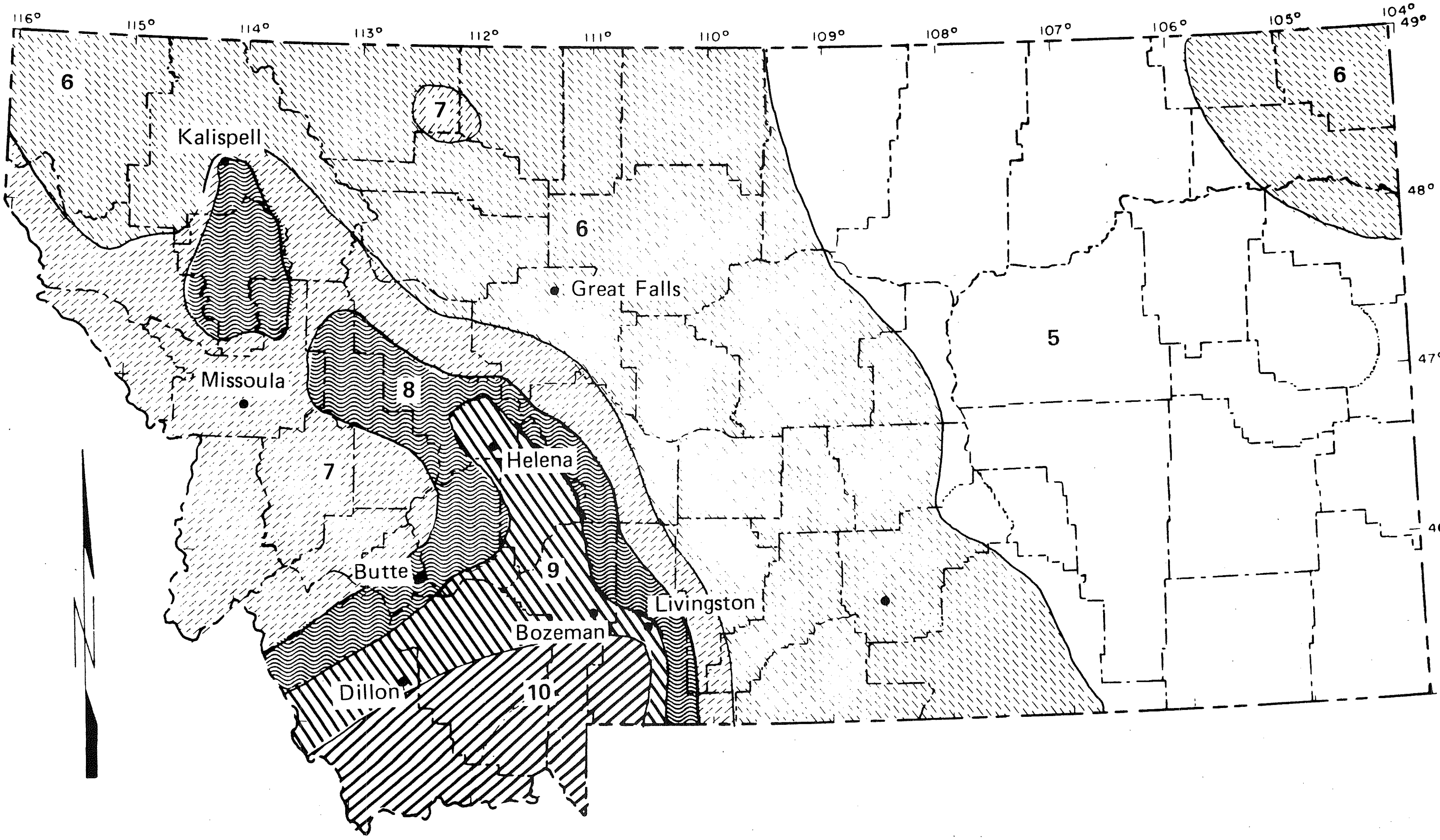

Figure 11 — Earthquake hazard areas of Montana based on both seismicity and distribution of active faults (from Bartholomew, Stickney and Henry, 1988); Patterns show expected Modified Mercalli Intensities for bedrock.

earthquakes. The frequency of major surface breaks on each fault segment, together with both the length of each fault segment and the frequency of historic earthquakes in the region, provide an estimate of the periodicity of major destructive ground-breaking earthquakes in Montana. Six trenches have been dug and described and provide preliminary information on 5 of the 41 known active fault segments of the 23 active faults in western Montana (Bartholomew, 1989a; Bartholomew and others, 1990).

The National Research Council has highlighted ground failures as the nation's most economically significant class of natural occurrences. Division personnel (primarily Edith M. Wilde and M. J. Bartholomew), in cooperation with the U.S. Geological Survey which provided a $30,000 grant, have compiled both a landslide inventory at a scale of 1:500,000 and a bibliography of landslides in Montana, and are generating an accompanying computerized data base for analysis of the landslides. Preliminary results were presented at the 37th Annual Highway Geology Symposium (Wilde and Bartholomew, 1987). The final product will be a 1:500,000 scale map of the entire state, showing landslide types, landslide-prone lithologic units, active faults, areas of known seismic activity, and landslides associated with construction problems or man-induced problems. These factors should assist interested users in assessing landslide hazards for proposed and current construction projects.

Special Projects

Staff members of the Division frequently have the opportunity to participate in international, national and regional professional geologic organizations. Early in FY89 the 8th International Conference on Basement Tectonics was held on the campus of Montana Tech. As a part of this conference, Sharon E. Lewis and Richard B. Berg served as co-chairmen of the field trip committee and as coeditors of the 195-page Guidebook volume that contains 11 papers and 11 field guides on the geology of Archean (basement) rocks of Montana and Wyoming as well as Mesozoic rocks in Montana, Idaho and Oregon (Lewis and Berg, 1988). Lewis (1988) also contributed one field guide. M. J. Bartholomew served as Conference chairman, and is the principal editor for the Proceedings Volume which contains 51 papers and 36 abstracts representing the 87 oral presentations at the conference. Twelve of the papers are on Montana geology and 13 deal with metallogeny and the tectonic setting of hydrothermal gold deposits. A $7,709 grant from the office of

Basic Energy Sciences, U.S. Department of Energy, and a $1,250 grant from the Montana Tech Research Committee are supporting the cost for preparation of the camera-ready copy of the book for commercial publication.

Also early in FY89 the Tobacco Root Geological Society held its 13th annual meeting and field trip at Dillon. Sharon E. Lewis was elected Vice President of the Society and Mervin J. Bartholomew led one field trip (Bartholomew, 1989b) for the conference. M. J. Bartholomew (Bartholomew, 1989c) also contributed to a Cordilleran field trip (T380) for the 28th International Geological Congress held in Washington, D.C. early in FY89. The Friends of the Pleistocene meeting will be held in southwestern Montana early in FY91. Bartholomew and others (in press) have contributed a paper for this conference. M. C. Stickney served as a session chairman at the 1990 Rocky Mountain Section meeting of the Geological Society of America.

Projects of the Mineral Resource Program

Information and Assistance Projects

The Division has three principal projects that provide information or offer assistance: 1) Montana Mine and Mineral Data System 2) National Coal Resources Data System and 3) Assistance to Small Miners. In addition, a list of Current Geological and Geophysical Studies is compiled and released annually (Berg, 1989; Vuke-Foster, 1990). It is used by researchers investigating the geology of Montana to see what research is in progress by USGS, MBMG geologists and by university faculty and students. The Division also prepares short pamphlets that provide information of a less technical nature on various aspects of geology and mining (Lewis, 1989).

Montana Mine and Mineral Data System

During the previous biennium the U.S. Geological Society provided a $40,000 grant to the MBMG to help prepare a data system containing information on metallic and industrial mines, prospects and minerals in Montana. The database for Silver Bow County, exclusive of the Butte district, was released as an open-file report during the last biennium. The database for Madison County was released as an open-file report (Derkey and Derkey, 1988) in FY89.

This database was designed as a reference and research tool assembled from: a) information in the files of the Bureau of Mines and Geology; b) published literature; and c) older filed information at both the U.S. Bureau of Mines and the U.S. Geological Survey. The Division plans to continue adding to this database on a county by county basis until the entire State is covered. Entries contains such information as the commodities produced, lithology and host rock, age of mineralization and production figures as well as other geologic and engineering data and references. The database can be used in conjunction with a graphics plotter to show the geographic distribution of different commodities and other parameters.

National Coal Resources Data System (NCRDS)

The National Coal Resources Data System, NCRDS, was established by the U.S. Geological Survey to assess the quantity and quality of United States coal resources. The system was designed to be used as a reference and research tool, as well as a way to provide consistent data to policymakers who decide upon the usage of coal resources. Under the NCRDS cooperative agreement (currently in its 8th year) the U.S. Geological Survey has granted the Bureau of Mines and Geology $371,500 to help prepare a comprehensive data base containing information on Montana's coal resources. Mark A. Sholes and Edith M. Wilde are the principal investigators for NCRDS.

The Bureau of Mines and Geology has a large amount of information available from in-house drilling projects and current geologic studies as well as a considerable amount of information from private sources. All the available information is being added to the existing data base. The data base requires the preparation of drill-hole information, measured geologic sections, outcrop descriptions, and chemical analysis for computer entry. In addition, all the data entered must be checked for accuracy and completeness, with corrections made as necessary. These data can then be used to derive other products to assess coal availability.

Two sub-systems were designed by the U.S. Geological Survey to provide an efficient system to utilize the available data base. The first system, a Program to Analyze Coal Energy Resources (PACER), was designed to provide a structure to the database files. PACER also produces various reports, charts and statistical records. The second sub-system, Graphic Analysis of Resources uses the Numerical Evaluation Techniques Program, GARNET. GARNET allows the user to create contour plots at specific map scales, estimate coal tonnage for an area, and perform other related tasks. GARNET provides a powerful tool for calculating resource estimates, while allowing enough flexibility to permit geologic interpretations to play a key role in those estimates.

Manuscripts on Coal Resource Evaluation of the Sidney and Glendive 30x60-minute quadrangles by Downey and Wilde, resulting from this project, will be ready for review in FY91. At the current time, two additional reports covering the Baker and the Wibaux 30x60-minute quadrangles are planned.

With the greatly enhanced computer capabilities that the Bureau of Mines and Geology now has, most of the work will be able to be done in Butte rather than having to use the USGS computer in Reston, Virginia - a costly process in both time and money.

Assistance to Small Mine Operators

The services provided by the Staff Field Agent, Robin B. McCulloch, cover a wide variety of engineering subjects that pertain to the mineral industry. The type of assistance ranges from: a) how to stake or patent mining claims; b) prices of metals; c) location and minerals found in mining districts or mines; d) how various types of mining, milling equipment is used; e) suggestions on what type of equipment is likely to work best for particular mining, milling or placer operation; to f) supplying lists of consultants, assayers, etc.

The Staff Field Agent wrote 28 mineral identification letters (a free service), in which individual samples were identified, and made 10 verbal reports to individuals identifying samples. In addition, 263 letters on other mineral-related topics were also written. Annually, the Staff Field Agent spends 50 percent of the time in the field assisting miners and giving presentations to diverse groups ranging from grade school or high school teachers and students to civic groups to mining groups to state and federal agencies such as the U.S. Forest Service or the Federal Reserve Board. The Agent provides short term assistance and advice, but for problems requiring more time, the questioner is referred to a consultant or specialists within Federal agencies. The Field Agent keeps abreast of mineral activity within the State through field trips, interaction with the U.S. Forest Service, BLM, MSHA, Department of State Lands, Montana Mining Association, and individuals.

The Field Agent is responsible for; 1) gathering the data for an annual directory (McCulloch, 1989b; in press) of mining activity in Montana (McCulloch, 1989d); 2) working with the U.S. Bureau of Mines Liaison officer to publish the chapter of Montana Minerals Yearbook (Rice and others, in press); 3) gathering data for presentation (McCulloch, 1988, 1989c) at the Northwest Mining Association Convention in Spokane in December of each year and gathering data for the annual mining review (McCulloch, 1989a, 1990).

Resource Assessment Projects

Metallic Mineral Resource Investigations

The scope of research on metallic mineral deposits ranges from syntheses of all deposits (Derkey, in press) to studies of commodities or individual mining districts or mineral deposits to methods used for exploration (McCulloch, in press).

A project initiated by R. B. McCulloch during this biennium will compile data to show the overall economic impact of the mineral industry on the economy of the State of Montana. This report will be published during the next biennium. R. B. McCulloch is also preparing a comprehensive summary of all active mines in the State of Montana.

Publication of a project, initiated during the last biennium by D. C. Lawson and M. J. Bartholomew, to replace the old report on gold placers of Montana (Lyden, 1948) with a modern report is expected during FY92. In addition to history, mining and geology of the deposits this report will also include a study of the purity of placer gold in which small nuggets are being analyzed by microprobe.

Nonmetallic Mineral Resource Investigations

The scope of research on industrial mineral deposits varies from syntheses of all deposits (Berg, 1989, 1990) to studies of specific commodities to studies of individual mineral deposits. The top priorities for the last few years have been a commodity study of barite and a regional study of talc.

Publication of the report on Barite in Montana (Berg, 1988) marked the culmination of a 10-year project. This is the most recent in a series of studies on non-metallic mineral commodities in Montana. These studies provide information that can be used by those engaged in exploration for these commodities and in some instances deposits of other minerals associated with the particular commodity.

Barite, a heavy, white mineral, is used as a weighting agent in drilling mud as well as in chemical and filler applications. Barite has been mined from deposits in the Missoula area and at one locality west of Kalispell. The largest deposits are in the Elk Creek-Coloma area in the Garnet Range northwest of Drummond.

By gaining an understanding of those factors responsible for the formation of known barite deposits, exploration for new deposits can be concentrated in those areas with the greatest potential. Field relations indicate that most barite veins are along faults where aqueous solutions have deposited barite replaced the country rock. Data on the concentration of barium in rocks of the Belt Supergroup and sulfur and oxygen isotopic ratios suggest that the probable source of the barite in these veins was barite in very low concentrations in the surrounding rocks of the Belt Supergroup.

During the last biennium, the results of an Assessment of Potential for Talc Deposits within the BLM Wilderness study area of the Ruby Range, southwestern Montana was released. This investigation was funded by a U.S. Geological Survey grant ($6000) for studies by Richard B. Berg. In addition, a special cooperative research study by Richard B. Berg and Professor Sakuro Honda of the Research Institute for Underground Resources, Mining College, Akita University, Akita, Japan is aimed at defining the distribution of chlorite occurrences and their relationship to known faults. Laboratory analyses include fluid inclusion studies on quartz veinlets contemporary with the formation of chlorite veins and detailed petrographic and chemical analyses of both chlorite and partly altered quartzofeldspathic gneiss. The purpose of these analyses is to place constraints on conditions of formation of chlorite and to develop a model for its deposition. This investigation also will determine whether this chloritic alteration is related to gold mineralization in the Silver Star and Rochester districts.

Energy Resource Investigations

Studies on energy resources range from syntheses of all Montana Coal deposits (Sholes and others, in press) to research on specific areas or on specific coal beds. Between 1982 and 1986 the United States Geological Survey funded a cooperative investigation for $213,000 to map and assess a part of Montana's coal resources. The studies included field mapping, core drilling, and the use of existing subsurface information. The data have been analyzed by standard techniques and with the National Coal Resources Data System (NCRDS) computer. Several reports from this investigation were previously published by the MBMG and during FY89/90 three 1:100,000-scale areas were published (Mathews and Wilde 1989; Sholes, 1988; Sholes and others, 1989).

An important feature of these studies has been the integration of stratigraphic and sedimentologic studies to provide reasonable interpretations of the coal stratigraphy. Coals are generally laterally extensive but variable. This lateral variability affects resource estimates and requires sedimentologic understanding for adequate resource estimates. Furthermore, coal characteristics are vertically and laterally variable within coal seams and at least some of these variations are related to the original depositional environment of the coal and the associated rocks. M. A. Sholes and Takuo Sugawara of Akita University, Japan, are studying such variability in an investigation of the characterization of coal for pyrolysis and desulferization.

Coal petrology is an important means for characterizing coal and initial studies were funded by the U.S. Geological Survey as part of the Coal Lands Mapping Investigations and NCRDS. The Knobloch Coal in the Ashland area was studied because the petrographic results can be combined with sedimentologic and chemical studies to provide a more comprehensive analysis of coal. This paper is part of a Bureau of Mines and Geology Special Paper, edited by M. A. Sholes to be published in FY91. This Special Paper contains eight papers with figures, cross sections, and maps on Montana coal, and includes reports by several Bureau geologists. It will present the latest stratigraphic and sedimentologic concepts for selected areas and some of the first petrographic studies of Montana coal.

During FY90 the Division began an investigation of the Cat Creek oil field. This work includes both regional mapping (Porter, 1990) and detailed work on faults and subsurface stratigraphy by W. John Nelson. The field work will be completed early in FY91 and results will be published during the next biennium. The study is aimed at understanding the tectonic development of the Cat Creek anticline and the effects on stratigraphy and petroleum accumulation in that region.

Projects of Educational Program

One staff member of the Division holds a joint appointment with the Department of Geological Engineering. Other staff members occasionally teach formal courses as well. The Division scientists also teach short courses offered on the Montana Tech campus, and give lectures to school, civic groups and mining organizations. For several years, Bureau geologists and hydrogeologists (R. B. Berg, J. L. Sonderegger, M. A. Sholes, L. G. Zeihen) have participated in a research exchange program with faculty of the Research Institute for Underground Resources, Mining College, Akita University, Akita, Japan. The work has involved research by the entire group for several weeks each year either in Japan or Montana. During FY90 the group met in Japan to summarize their work. Publication of the results is expected during the next biennium.

Also, in FY90, Richard B. Berg has participated in a one-year exchange program with the Illinois State Geological Survey, and W. John Nelson from the Illinois Survey is working at the Bureau of Mines and Geology until early in FY91. R. B. Berg, an expert on Montana non-metallic mineral resources, is studying the Tripoli clay deposit in Illinois, and Nelson is studying the Cat Creek oil field in Montana. Such exchanges help to stimulate new research and continuing professional growth.

Short Courses and Lectures

Three short courses relating to the mineral industries are offered annually in the spring. The Staff Field Agent, R. B. McCulloch, generally serves as coordinator and, along with other Division staff also serves as an instructor. A two-day placer mining short course is designed mainly for those not familiar with placer mining. A two-day prospecting course is also offered at the introductory level. A three-day course on practical development, mining and milling is offered at a more advanced level.

Lectures given to school classes, mining groups, and mineral collectors deal with some aspect of geology or the mineral industry. The Staff Field Agent, R. B. McCulloch, delivered numerous talks to schools and talks to mining groups during the biennium. M. C. Stickney, Director of the Earthquake Studies Office also presents numerous talks.

As part of its outreach program to high-school students, Montana Tech hosts an annual Expanding Your Horizons conference which 200-300 students attended in both FY89 and FY90. Approximately 50 professionals from various fields participated in the program each year. S. E. Lewis served on the speaker committee both years, chaired the committee in FY89, and participated in both conferences.

Mineral Museum and Mineral Research Collection

Each year more than 16,000 people visit the Montana Tech Mineral Museum, which contains a large collection of excellent mineral specimens. The Mineral Museum is under the supervision of R. B. Berg and L. G. Zeihen of the Bureau of Mines and Geology. In recent years, the main efforts have been directed at improving the collection of mineral specimens from Idaho and Montana, improving displays, and conducting tours for groups through the Museum. The collection contains many very fine specimens.

The Museum suffered severe damage from a fire on February 7, 1990, and has been closed for repair for the last half of FY90.

A somewhat related activity of the Montana Bureau of Mines and Geology is the curatorship of an extensive collection of approximately 15,000 specimens from the Butte district donated to Montana Tech by the Anaconda Company. Unlike the collection displayed in the Mineral Museum this collection is mainly a research collection. It is now housed in the Mill Building on campus.

Research Laboratory

The Anaconda Company previously donated essentially all of the equipment (with a value of more than $250,000) from their research lab to Montana Tech. During FY89/90 this equipment was set up for use in the Mill Building on the Montana Tech campus. This lab will be used primarily for sample preparation, mineralogical analysis and other procedures.

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HYDROLOGY DIVISION

Wayne A. Van Voast
Division Chief

Variety best describes the Hydrology Division's programs over the past biennium, corresponding with the broad diversity of hydrologic problems and opportunities in Montana. Projects in the Division's Butte and Billings offices were active in hydrogeologic aspects of oilfield exploration and wastes, mining activities and exploration, agricultural land uses, agricultural chemicals, hazardous-wastes, ground-water recharge and development for irrigation, and broad dissemination of general hydrologic data (Figure 1).

Oilfield reserve-pit problems, brine disposal, and their effects on soil and ground water were objects of studies in Richland and Sheridan Counties. Effective and cost-efficient techniques of plugging seismic shot holes and mining-exploration drill holes were being examined in southeastern Montana.

Through several cooperative agreements with other agencies hydrologic aspects of hazardous wastes and mining were addressed during the biennium. An agreement with the Montana Department of State Lands established a cooperative program in which the Hydrology Division has provided hydrogeologic expertise on problems associated with mine permitting and reclamation. Under an agreement with the Department of Interior, standards defining the adequacy of hydrologic data for Bureau of Land Management coal leasing decisions were written. Under a series of cooperative agreements with the Montana Department of Health and Environmental Sciences, the Hydrology Division provided oversight activities on Superfund and National Priority List sites where environmental research or remediation work was being conducted. Among these were a transformer storage area and an abandoned pole-treatment site in Butte, and an abandoned oil refinery and timber-processing plant in Missoula, where hazardous wastes are believed to have been released to shallow ground water over many decades. Under a similar cooperative agreement, the Hydrology Division conducted a long-term, high-discharge pumping test of the Travona mine shaft in Butte. The testing determined quantity and quality of water that must be pumped to stabilize water levels at safe depths there.

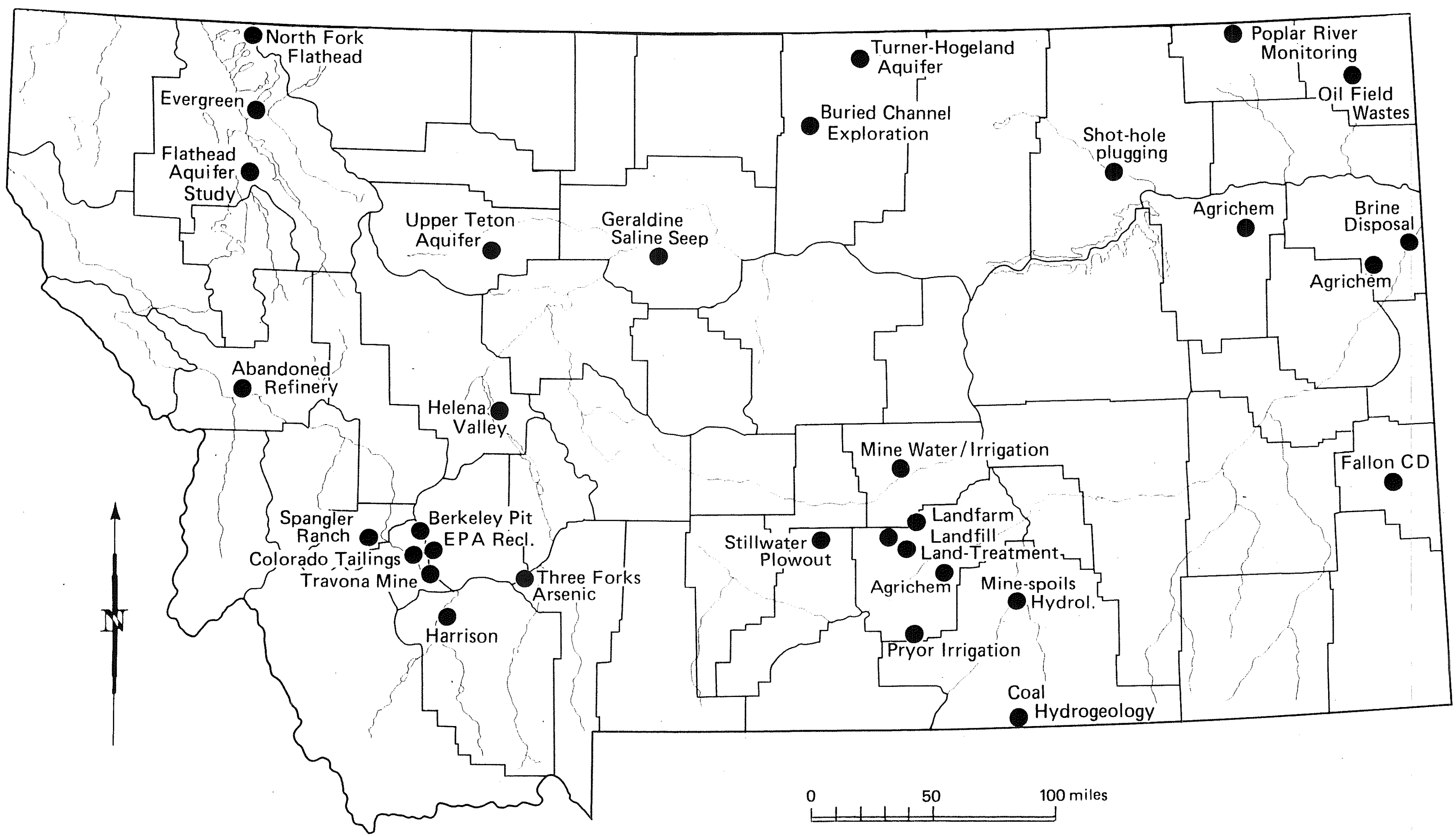


Figure 1—MBMG Hydrology Division field projects 1988-1990.

Research into various hydrologic aspects of mining was conducted throughout the biennium. In the coal fields of southeastern Montana, two interrelated projects on the effects of surface coal mining on ground-water levels and quality were conducted, and in northeastern Montana a hydrologic monitoring program near a coal mine and a power-generation plant in Saskatchewan was maintained. Also, a research inquiry into potential hydrologic problems from deep non-plugged uranium exploration holes near Whitehall and near Harrison was made.

Numerous evaluations of the influences on water quality by agricultural activities were in progress the past biennium. An ongoing study of plow-out and saline-seep reclamation practices in Stillwater County was continued, and the use of lime in reclamation of heavy-metal-contaminated soils in the Deer Lodge valley was evaluated. A study and long-term monitoring of the extent and intensity of agricultural-chemical (pesticides and nutrients) contamination of shallow ground water across the State was begun, and several studies evaluating detection techniques and hydrologic mobility of agricultural chemicals were completed.

Safe and conservational development of ground water for beneficial use is also an objective of the Hydrology Division. In that regard, a project to replenish shallow ground-water resources by inducing recharge through modified land-use practices was begin in northern Blaine County. Another project was begun to find new supplies of water for irrigation from aquifers near Pryor, and another continued to examine irrigation-water availability in abandoned underground mines near Roundup.

Hydrology Division personnel have also been active in projects and programs to provide technical service and data to individuals, agencies, and companies throughout Montana. Most noteworthy is the Ground Water Information Center (GWIC), maintained to house and disseminate well logs and water-quality data for the entire State. Many hundreds of inquires for ground-water information were answered during the biennium by Butte and Billings office personnel using the GWIC.

Geohydrologic Evaluation of the Helena Valley

by

John Sonderegger

Shallow aquifers underlying the Helena Valley (Figure 1) are the sole sources of domestic water supplies for 13,000 residents. Deeper aquifers are potential sources of water for irrigation, industrial, and municipal supplies. Population growth in this vulnerable area could result in increased contaminant load to the shallow aquifer from increased septic-tank density, industrial-waste discharge, accidental spills, and other anthropogenic causes. Additional pumpage from deeper aquifers could alter flow systems and cause vertical migration of contaminants from shallow aquifers to deeper parts of the system.

In recent years, numerous incidents of ground-water contamination in the Helena Valley have been reported. As septic tank densities have increased, the number of wells contaminated with bacteria has risen. Nitrate concentrations exceeding background levels have been observed in wells throughout the valley. Gasoline and diesel spills from pipelines, storage tanks, and refueling facilities have contaminated shallow aquifers at several sites. Ground water near landfills contains organic and inorganic compounds associated with solid wastes. Obviously, ground-water contamination problems exist in the Helena Valley and the number of reported incidents of contamination increases each year. However, knowledge of the aquifer system is inadequate to assess impacts to the aquifer system.

The purpose of this study is to develop the data framework needed to build a comprehensive management program to protect this irreplaceable resource. The study is designed to expand and extend current knowledge of the ground-water system through a systematic program of data collection, research, and information assimilation in order to develop a thorough understanding of ground-water flow paths, recharge and discharge, and sources of contamination.

The study is being conducted as a cooperative effort involving Lewis and Clark County, University of Montana, Montana College of Mineral Science and Technology, Montana Bureau of Mines and Geology, and the U.S.Geological

Survey. Each of the participants will contribute manpower, equipment, and funding and will assume responsibility for specific aspects of the overall study. Lewis and Clark City-County Board of Health will administer the study. The U.S. Geological Survey will coordinate data collection and analysis and prepare the final report. University of Montana and Montana College of Mineral Science and Technology will coordinate graduate-student research and collaborate with the U. S. Geological Survey in technical oversight and integration of specific work installing test wells, assisting in aquifer tests, providing laboratory services, and providing technical support and oversight.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

1. Montana Department of Natural Resources and Conservation-Resource Indemnity Trust Program.
2. Lewis and Clark County Board of Health
3. U.S. Geological Survey,Water Resources Division*

*Project lead is with the U.S. Geological Survey

Coal-Lands Hydrology

by

Wayne Van Voast

Energy is not the only resource that southeastern Montana coal can provide. The coal beds, because of their generally fractured characteristics and broad areal continuities, are commonly the most accessible and widely used aquifers of the region. In this semi-arid climate, many inhabitants are almost totally dependent upon ground water for stock and domestic supplies, and in many places it is obtained from coal beds that will be removed by mining. Impacts of mining upon water supplies that are vital for agriculture are causing concern on both State and federal levels.

More than 32 billion tons of lignite and subbituminous coal are present within Montana's portion of the Fort Union coal region. Twenty-six coal beds have been identified, having thicknesses between 3 feet and 75 feet, and underlying almost 800 thousand acres. Thus far, the subbituminous beds have been the primary objects of development because of thickness, areal persistence, low-sulfur content (generally less than 1 percent), and shallow depth. Although coal has been mined in the region by individuals and small operations for many years, most of the production was from underground mines that had little noticeable effect on the land or water. Large-scale surface mining has now become prevalent in the subbituminous fields; since 1968, six surface mines have been opened and numerous others are in the planning stages.

The need for ground-water information became important with the advent of these large-scale surface mining operations, whereby the Montana Bureau of Mines and Geology began programs of hydrologic study near the Rosebud, Big Sky and Decker Mines (Figure 2). Information on many important hydrologic aspects of surface mining has been developed from these studies and has been applied extensively by State and federal regulators on decisions regarding leasing, data standards, mine permits, methods, and reclamation. Also, a network of strategic observation wells evolved and a sophisticated, coal-field-specific, computerized data system was generated. The data file contains water-level and-quality data, in many cases covering 15 or more years of record.

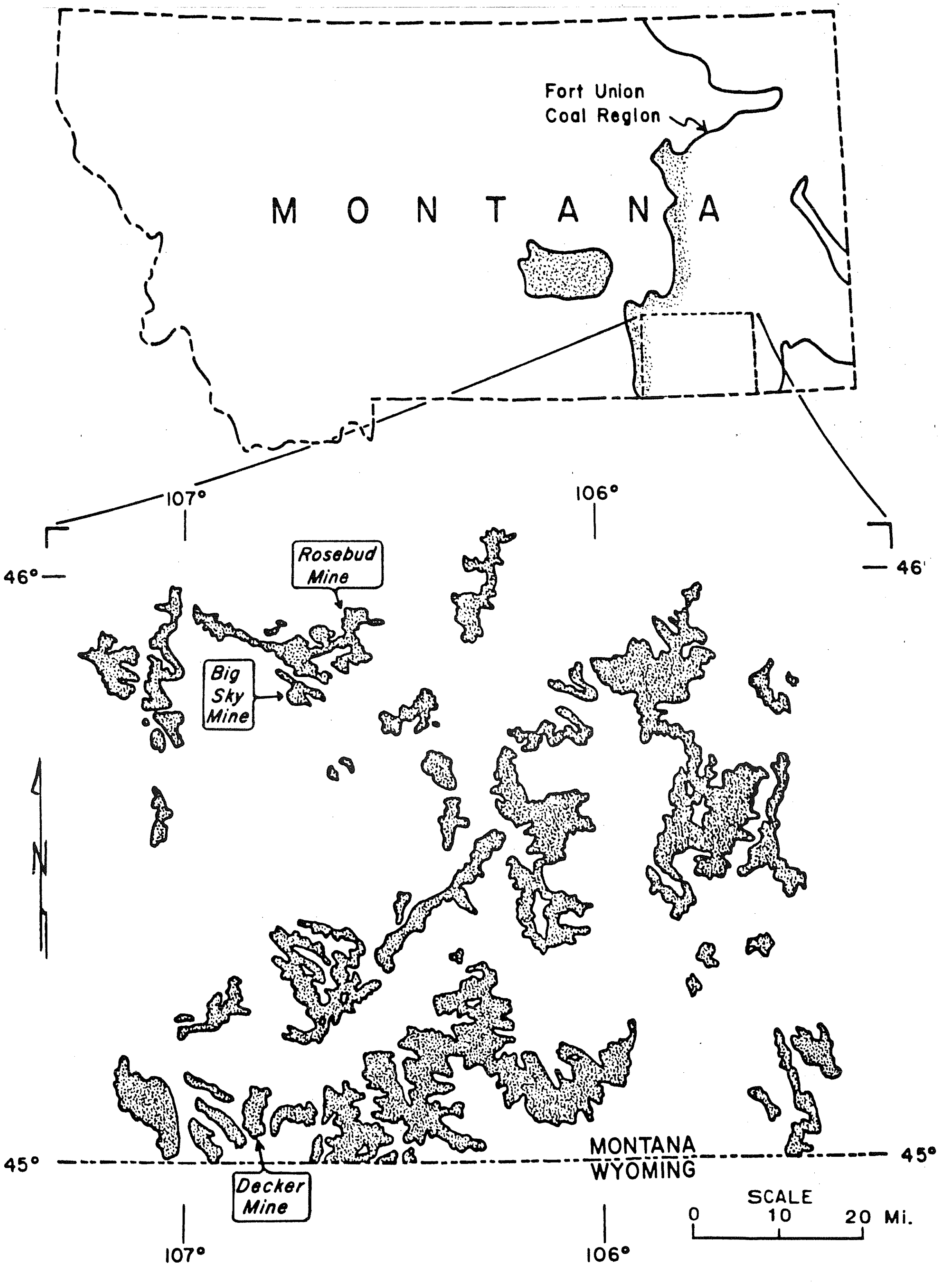


Figure 2. The Rosebud, Big Sky, and Decker mine areas are in the subbituminous portion (stippled pattern) of the Fort Union coal region.

Ground-water levels near mines along aquifer outcrops, such as near Colstrip, do not change substantially during mining. In contrast, mines that have penetrated a more central part of a flow system near Decker have caused potentiometric declines over an area more than 15 miles long and 5 miles wide. Although the large area of drawdown passes beneath valleys containing perennial streams and alluvial aquifers, alluvial water-table changes have not occurred. Confining beds of clay above the coal-bed aquifers effectively isolate the decreased hydrostatic pressures from shallower ground water.

As backfilling follows coal removal, ground water reenters spoils at the mines. Greatest resaturation thus far has occurred through recharge by lateral flow from undisturbed aquifers. Where vertical gradients are favorable, upward flow (possibly through pre-mining test holes) can be significant. Whether by test holes or other means, hydraulic connection between the mines and deeper aquifers is documented by hydrostatic-pressure changes that occur during mining. Substantial ground-water flow in spoils occurs along mine-floor aquifers where a variable thickness of wasted coal and coarse rubble have been covered by finer-grained materials. Evidence is very strong that the spoils do not act as barriers to ground water flow and, in some places, can provide adequate quantities of water for stock or domestic use.

Water quality in new mine spoils is highly diverse because of the variable distributions of soluble salts after backfilling. With resaturation and the establishment of new flow patterns, water quality seems to become dependent on a balance between introduction of new salts through recharge and the flushing of salts by ground-water flow. At some wells at the Rosebud mine, recharge from the surface is introducing new salts as fast (or faster) than they can be flushed out. At others wells, such as near a local surface basin, very active recharge and ground-water flow appear to have already flushed most available salts. At some wells in West Decker spoils, trends toward decreasing concentrations of dissolved solids are being established; recharge from adjacent undisturbed aquifers is beginning to flush salts from the mine-floor aquifers.

If trends for progressively decreasing dissolved-solids contents should become apparent at several additional monitoring sites, better projections of the time needed to approach pre-mining water-quality conditions can be made.

The area of hydrostatic-pressure declines near West Decker continues to broaden, providing important new information on cumulative mining impacts. Important information for predictions of post-mining water-quality trends seems to be developing as well, and should be reassessed as new data become available.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and other support from:

1. Montana Coal Board
2. U.S. Bureau of Land Management

Hydrologic Data Adequacy Standards for the Fort Union Coal Region for U.S. Bureau of Land Management Coal-Leasing Decisions

by

Wayne Van Voast

The U.S. Bureau of Land Management has been required by Congress to develop uniform standards of resource and environmental data for their coal-leasing criteria nationwide. To comply, BLM is forming task forces to draft pre-leasing data standards on geology, air quantity, hydrology, soils wildlife, cultural resources, reclamation, and socioeconomics. Through nomination by the Governor's Office and a request by BLM, Wayne Van Voast (MBMG) has been writing hydrology standards for coal regions that include Montana and adjacent states.

The first region under BLM nomenclature for development of standards was the Powder River Coal Region, which includes all Fort Union subbituminous coal beds in Wyoming and Southeastern Montana. Those standards were completed and approved as official BLM criteria in November, 1987. They define the numbers and types of hydrologic data and the levels of interpretation that BLM must utilize for any coal-leasing decision in that region.

Similar standards were finalized for the Fort Union Coal Region (BLM nomenclature) that includes all lignite coal in North Dakota and eastern Montana. Work leading to the final standards included literature searches, manuscript preparation, meetings with North Dakota and Montana colleagues, and extensive peer review. Following announcement in the Federal Register and a 45-day public comment period, the draft was presented to State Governors' representatives and BLM administration at their annual Coal Team meeting in October, 1988.

The hydrologic standards written by MBMG not only will assist the BLM in compliance with a Congressional directive, but they will help assure that good pre-mining hydrologic data are collected that will be of tremendous value throughout the mining and reclamation processes, and which will help to assess the effects of future development.

Sources of Funds and Support

Montana Bureau of Mines and Geology Appropriated funds matched with supplemental funds from:

1. U.S. Bureau of of Land Management
2. Governor's Office

Sheridan County Reserve Pit
and
Brine Disposal Assessment

by

Jon Reiten

This project, sponsored by the Sheridan County Conservation District, is located in the eastern third of Sheridan County (Figure 1), more specifically in the Flat Lake, Goose Lake, Divide, Clear Lake, and Katy Lake oil fields, in addition to other selected sites in the vicinity of those oil fields.

Ground-water contamination from oil-related activity has been a widely reported, though never technically verified, problem throughout the history of the industry in the area. The problem was first brought to the attention of state officials in 1975. These and other oil-related problems resulted in the formation of the Northeast Land and Mineral Owners' Association. The attention brought to contamination problems has resulted in regulators' requirements for lining reserve pits; tighter restrictions on saltwater disposal wells; and requirements for surface casing in exploration wells using saltwater. These requirements in Sheridan County may have lessened the severity of the contamination resulting from those practices. To date no studies have been conducted to determine the subsurface extent of the problem.

Off-site, disposal facilities for oil-field, drilling mud have been proposed by local government officials as one alternative to reduce or eliminate subsurface contamination. Before such disposal could be required; however, it is necessary to determine whether the problem is sufficiently widespread and serious, and in what types of cases off-site disposal should be required.

The objectives of the study are:

1) to assess the extent and severity of shallow, ground-water contamination resulting from the disposal of oil field wastes in these areas, primarily drilling muds and saltwater brines;

2) to develop a broadly applicable, cost-effective methodology for identifying and defining subsurface contamination as well as a matrix ranking system based on existing data for assessment of existing potential groundwater contamination at any given location;
3) to identify areas of existing contamination; and
4) to develop and assess technical alternatives and cost estimates for reclamation, and to review alternatives to current disposal practices to determine if there are practical methods by which future contamination can be reduced or eliminated.

The specific objectives of the study are being assessed by a multi-phased research plan that started with a general inventory of about 300 potential sites of oil field contamination. That phase was followed by a more detailed hydrogeologic investigation of 20 "high" risk sites identified during the inventory. The final project phase consists of detailed site investigations in an area of extensive ground water and surface water contamination near Goose Lake.

The site classification was based primarily on age of site, reported spills, and current site conditions. Age of site appears to correlate well with occurrence of contaminated ground water. Prior to the mid-1970's much less care was used when disposing of oil field wastes compared to after the mid-1970's. Landowner reports of spills, discharges and leaks of oil field wastes also correlate closely with documented, ground-water contamination. The current site conditions including sterile soil or weed infestations caused by brine contamination also are good indicators of ground-water contamination.

The most extensive contamination identified in the Sheridan County Brine Assessment is in outwash gravels near Goose Lake. The greatest amount of contaminant migration identified is downgradient of oil well sites. Chloride concentrations at a well about 2000 feet downgradient of former evaporation pits were measured at 36,500 mg/L from a sample collected in October 1989. Preliminary results of trace metal analyses indicate lead concentrations above drinking water standards in 8 out of 11 samples from near the test site. The contaminant plume was mapped over an area 6 miles long and more than 1 mile wide. Vertically integrated water samples from within the contaminant plume indicated a strong density contrast from the water table to the base of the contaminated aquifer. For example, the chloride concentration varied from 8290 mg/L near the top of the aquifer, to 19,970 mg/L near the middle of the aquifer, to 24,000 mg/L near the base of the aquifer. These density gradients were observed over a saturated thickness of about 12 feet.

Although ground-water contamination was not traced past the original study site, field water samples were collected from several lakes in the area. The lakes contain sodium sulfate type water with typically low natural chloride concentrations based on samples from nearby lakes not adjacent to oil field development. Chloride concentrations in lake water generally declined with distance from the probable contaminant source. A pond adjacent to the disposal site contains water with an average chloride concentration of about 15,000 mg/L. The unnamed lake that is a northwest extension of Goose Lake contains water with a chloride concentration of 4,500 mg/L. Goose Lake contains water with a chloride concentration of 3,400 mg/L. The previously observed density contrasts probably result in higher chloride concentrations in deeper portions of the outwash aquifer below and adjacent to the lakes in the Goose Lake chain.

The southern part of Goose Lake overlies the Clear Lake aquifer. The Clear Lake aquifer is tapped by high yield irrigation wells both north and south of Goose Lake. Flow in the Clear Lake aquifer is south and west towards Medicine Lake. The interconnection between shallow tributary aquifers and the deeper Clear Lake aquifer is poorly defined. Consequently, impacts of salt loading from the shallow portions of the outwash aquifers cannot be predicted.

The preliminary results of the project indicate disposal methods may have to be more restrictive in glaciated regions of Montana because the near-surface geology is much more complicated than in non-glaciated regions. This makes the decision on the proper disposal method difficult with a field visit, and possibly test drilling, required.

Many of the techniques used in this project to identify and rank the contamination potential of oil field sites such as landowner interviews, EM-Surveys, and site assessments will work very well in most other parts of the state.

Sources of Funds and Support

Montana Bureau of Mines and Geology -- Appropriated funds matched with supplemental funds from:

1. Montana Department of Natural Resources and Conservation -- RIT program
2. Sheridan County
3. Sheridan County Conservation District
4. Soil Conservation Service -- Plentywood, MT

Impacts of Oil Field Wastes on Soil and Ground Water in Richland County, Montana

by

Jon Reiten

The resurgence of oil field development in the Williston Basin of eastern Montana during the late 1970's and early 1980's coincided with a time of greater environmental awareness and concern among the local residents. Consequently, regulators and oil company staff were being asked to consider the toxicity of the oil field wastes, the methods of waste disposal and potential damages to soil and water resources.

Initially, more than a dozen sites were evaluated, including former evaporation pits, injection wells, mud disposal sites, and reserve pits. Most of these sites were originally brought to the attention of the Montana Bureau of Mines and Geology (MBMG) by members of the Northeast Montana Land and Mineral Owners' Association. Four sites were selected for further hydrogeologic and soils studies (Figure 1). Hydrogeologic research focused on the Hunter site and the Iverson site. Soil research was conducted at these sites plus the Propp site and the Watt site.

Waste drilling mud had been buried at the two sites selected for more detailed hydrogeologic investigations. The Hunter site, located 3 miles northwest of Fairview, Montana, about 300 feet above the Yellowstone River valley, consists of centralized disposal pits that were used for off-site disposal of waste drilling mud. The centralized facility had been developed without prior geologic investigation or state authorization. The Iverson site, located 3 miles north of Sidney, Montana, in the Yellowstone River valley, consists of a reserve pit reclaimed by trenching in 1982. Previous hydrogeologic investigations at this site identified a brine plume originating at the reserve pit.

Soil studies were conducted at all four research sites. The only contaminated soil at the Iverson site was a small area directly overlying the reserve pit and no more than a cursory evaluation was conducted. Soil contamination at the Hunter site was more extensive; consequently, research was more intensified. Soil testing and reclamation were conducted at the Propp site where reserve pit leachate has damaged soils on more than 1 acre of bottom land. Soil testing at the Watt site identified about 5 acres of damaged soils. The soil damage appears to have been caused by disposal of reserve pit wastes in an area prone to saline seeps.

The potential for soil and water contamination from oil field activities depends upon regional geologic setting, site-specific, geologic (drilling) conditions, and methods of waste disposal or containment.

Regional geologic conditions control the geochemistry of fluids produced in association with the hydrocarbons. Many Montana oil fields produce water containing relatively low concentrations of dissolved solids. Consequently, potential impact to soils and shallow aquifers is minimal. In contrast, produced water from the Williston Basin is commonly highly concentrated in dissolved solids, thereby creating a greater risk of degrading shallow aquifers and damaging soils.

Regional geology and site-specific, drilling conditions combine to dictate the types and concentrations of various additives used in constructing the optimal drilling fluid. Many of the additives contain trace metals or other materials that can potentially degrade shallow aquifers and damage soils.

Prior to the mid-1970's many of the reserve pits were left open and used for storage and disposal of produced brines or simply backfilled. This method of backfilling commonly left surface depressions and a generally unstable land surface. Since the mid-1970's the pits have been reclaimed by a variety of methods. The most common method is trenching or "spider-legging" which results in waste disposal in unlined trenches. One consequence of the trenching method of reclamation is the potential for contaminating shallow aquifers. Other waste disposal methods used in the last ten years include offsite disposal of the waste mud and solidification of the pits.

The following results directly address the initial study objectives:

1.) "Lost" formation fluids from Williston Basin oil fields contain high concentrations of sodium chloride salts. Calculated dissolved solids of these brines range from 100,000 mg/L to more than 300,000 mg/L.

Trace constituents are also present at high concentrations in the brines. High concentrations of boron, lithium, bromide, and strontium are the result of geochemistry of brines associated with oil-producing zones. High concentrations of silver, cadmium, lead, chromium, barium, aluminum, nickel, and zinc are probably the result of drilling additives. Several of these constituents are found at levels exceeding drinking water standards in waste drilling mud.

2.) Brine plumes are highly mobile, and movement is dominated by site-specific, hydrogeologic conditions.

At the Hunter site, brine plumes move vertically through the unsaturated zone and develop when rainfall or snowmelt infiltrates through the salt-saturated, drilling muds, thereby mobilizing salts into the recharge water.

At the Iverson site, brine plumes move horizontally and are remobilized during summer months when the seasonally high water table intersects the buried reserve pit.

3.) Site-specific, hydrogeologic conditions impact the dispersion and dilution effects.

At the Hunter site mechanical dispersion in the unsaturated zone has caused mixing of uncontaminated recharge water with recharge water contaminated by the salts. The product of the dispersion is to dilute the concentration of the plume.

At the Iverson site mechanical dispersion in the saturated zone has caused mixing of uncontaminated water with aquifer water contaminated by the salts. Most of the dispersion and dilution occurs in the top half of the aquifer. Wells in the lower part of the aquifer show little evidence of brine contamination.

4.) The contaminant plume at the Hunter site is sufficiently diluted for stock or domestic use by the time it intersects the water table.

The contaminant plume at the Iverson site is sufficiently diluted for stock or domestic use within a few hundred feet of the site. As precipitation and recharge were below average during the study period, these results may not represent normal conditions.

5.) Most cases of oil-field-related, soil contamination are commonly either at too large of scale to be within the context of this project or too small of scale to be considered a significant problem.

Soil sampling at the Iverson site detected limited contamination that was restricted to the area immediately above the reserve pit. Consequently, no reclamation was conducted at that site.

Contamination was more extensive at the Hunter site with salt crusts exposed at the surface and depressions overlying the disposal cells. Smoothing the land surface over the pits, covering exposed salt crusts with topsoil, and revegetation were the reclamation methods conducted at this site.

The damaged soils at the Propp site were more extensive and reclamation methods were designed to leach salts deeper into the soil profile by applying sulfuric acid and excessively irrigating the site. Unfortunately, high summertime water levels mobilized the salts up to the surface by capillary action reducing the effectiveness of the leaching experiment.

Damaged soils at the Watt site cover about 5 acres. Saline seeps developed in a complicated geologic setting have mobilized reserve pit salts. Investigations are being continued at this site by the Montana Salinity Control Association.

Other recommendations and observations are:

1.) There is a high potential for degradation of ground water resources and damaging soils when reserve pits are reclaimed by trenching in areas having high water tables such as flood plains, alluvial terraces and saline seeps. Where water tables are within a few feet of the land surface, soils are damaged when salts are transported to the surface by capillary action. In addition, salts are periodically dissolved from the wastes and degrade aquifer water quality. Brine saturated reserve pit wastes should be removed from areas having high water tables and disposed of at properly engineered centralized disposal facilities.

2.) Several methods are available for decreasing further soil and water contamination from improperly reclaimed reserve pits including:

   a.) Excavating and removing the drilling wastes from critical sites.

   b.) Excavating and diluting the wastes by washing with fresh water and injecting the waste liquids into non-potable aquifers.

c.) Establishing an in situ dilution process using methods such as infiltration galleries and irrigation.

d.) Encapsulating the waste muds.

e.) Mounding and capping reserve pits.

3.) The oil industry should be encouraged to decrease the amount of wastes produced by promoting recycling spent fluids. Recycling of drilling fluids has been demonstrated as a economical alternative to environmentally-sound waste disposal.

4.) Although significant localized contamination from oil field wastes has occurred, widespread degradation of soils and shallow aquifers has not developed in Richland County. Dilution of salt plumes by mixing and dispersion in both the unsaturated zone and saturated zone mitigate the impacts of contamination. In general, this restricts significant contamination to within several hundred feet of the source.

Sources of Funds and Support

Montana Bureau of Mines and Geology -- Appropriated funds matched supplemental funds from:

1. Montana Department of Natural Resources and Conservation -- RIT program
2. Soil Conservation Service -- Sidney, MT

Montana Bureau of Mines and Geology

and

Montana Department of State Lands

Cooperative Agreement

by

John R. Wheaton

The Montana Bureau of Mines and Geology (Bureau) is contracted by the Montana Department of State Lands (DSL) to provide hydrogeologic expertise. The DSL provides regulatory oversight of mining and related activities in addition to other natural resource planning and management activities.

The Bureau provides shallow test drilling, well drilling, ground-water monitoring, hydrologic testing, hydrogeologic studies, and geotechnical expertise to the Reclamation Division, MDSL. These services are provided on a project-by-project basis with the Abandoned Mine Reclamation, Coal and Uranium, Hard Rock, and Opencut Bureaus. The parties of the agreement have as their objectives to:

A. Coordinate activities
B. Increase efficiency
C. Facilitate day-to-day operations
D. Share skills and knowledge
E. Share equipment and facilities
F. Reduce costs

The Bureau performs a strictly non-regulatory function by providing hydrologic interpretations which the DSL uses to make regulatory assessments.

The Bureau and DSL formally entered the agreement during September 1989. Since that time hydrology has been a key issue at several coal mines in eastern Montana. Meridian Minerals has begun mining coal in a test pit in the Bull Mountains and has proposed a large underground mine. Decker Coal Company has requested a mine plan change. Spring Creek Coal Company, lacking sufficient supplies of water, requested DSL permission to tap a new ground-water source. Both Western Energy Company and Peabody Coal Company requested mine-plan changes that involved alluvial aquifers. Knife River Coal Company requested an extension to the mine area.

John Wheaton (Bureau) provides the hydrogeologic interpretations which are used by DSL personnel in making regulatory decisions on these and other issues. In addition to coal-mining related issues, hydrologic input has been provided to DSL by the Bureau on gravel-pit operations and uranium-exploration programs.

During the first year of this agreement, mutual benefits have been recognized by both the Bureau and DSL. In the future, additional Bureau staff members will become involved in the program.

Source of Funds and Support

Montana Bureau of Mines and Geology funds matched with supplemental funds from:

1. Montana Department of State Lands

Ground Water from Abandoned Mine Workings for Irrigation and Instream Flows, Lower Musselshell River

by

John R. Wheaton and Jon C. Reiten

A possibility exists for developing an off-stream, underground storage reservoir in the Musselshell River basin, near Roundup (Figure 3). If developed, the reservoir would help alleviate water shortages which are currently experienced in the basin during 80% of all years. The site consists of several abandoned underground coal mines comprising a vast labyrinth of entries, rooms and haulageways. Ground water presently floods most of the workings and may be extractable to supplement the Musselshell River flow during times of greatest demand. The underground reservoir could be replenished by natural recharge from alluvium and other adjacent aquifers, or by artificial recharge from excess Musselshell River flows during times of lower demand. The reservoir would be administered by the Deadman's Basin Water Users Association, which counts among its 152 members the towns of Roundup, Melstone, and Ryegate.

The project is evaluating the feasibility of development of the underground reservoir through water quantity and water-quality investigations. All of the current mine samples contain water dominated by Na and SO4 with dissolved solids values ranging from about 1,300 to 5,200 milligrams per liter. Polychlorinated biphenyls were not detected in any of the samples. Pentachlorophenol was detected in a sample collected from the Roundup No. 3 Mine.

Water-level data indicate the mines are, for the most part, hydrologically isolated from one another. The one exception being that the Roundup No. 3 East and the Prescott Mine have similar water levels and fluctuations. A head difference for mine waters of about 60 feet was measured over the study area from the south to the north and northeast. This is consistent with the local topography. Water levels at different wells within individual mines are the same elevation. This implies that the hydraulic integrity of the individual mines is still intact.

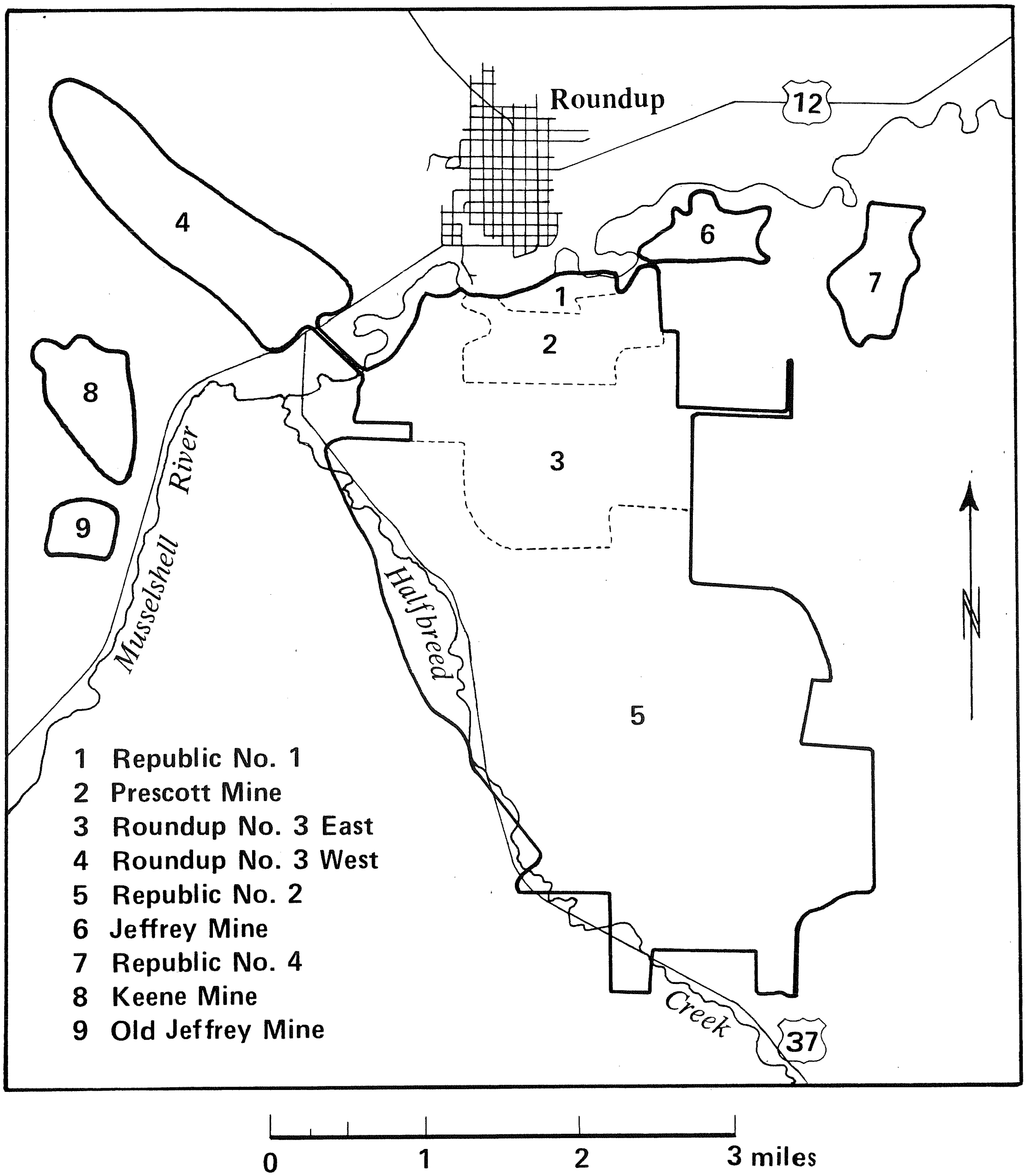


Figure 3. Areas underlain by abandoned underground coal mines near Roundup, Montana.

Additional concerns that are being addressed by the project are: the possibility of subsidence, potential for deleterious impacts to local ground-water users, and poor economics of developing the underground reservoirs. A test pumping of the Jeffries Mine during December, 1989 removed 24 acre-feet of water. No other mines were affected by the pumping, however, water levels declined in 2 of the 5 private wells overlying the mine.

During the test pumping, the Jeffries Mine water level dropped about 45 feet and recovered to pre-pumping levels within about three weeks after the termination of pumping. Future work on this project will continue to assess the potential for development of the underground reservoirs.

Sources of Funds and Support

Montana Bureau of Mines and Geology Appropriated funds matched with supplemental funds from:

1. Department of Natural Resources and Conservation -- Resource Indemnity Trust Program

Water Resources of the Upper Pryor Creek Basin, Crow Indian Reservation, South-Central Montana

by

John R. Wheaton

Thousands of acres in the upper Pryor Creek basin are irrigable. However, the quantity of surface water available is not adequate to supply water to all irrigable acreage. Ground-water supplies are required to supplement surface-water supplies. The quantity, quality and availability of ground water and the ground-water surface-water relationships have not been previously investigated nor described. This five-year project will define the hydrologic resources and relationships in the upper Pryor Creek basin.

The primary aquifers which may provide large quantities of water for irrigation use are the Quaternary sand and gravel deposits beneath the valley of Pryor Creek, Cretaceous sandstones, and Mississippian carbonate rocks. Private wells in the area generally produce between 5 and 40 gallons per minute, are completed in shallow gravel or sandstone, and provide domestic or stock water. Regionally, the Mississippian age, Madison Formation has been tapped for irrigation water at Bowler Flats.

Dissolved solids, calculated from analysis of water-quality samples collected from shallow wells, springs and Pryor Creek, range from 200 to 720 milligrams per liter (mg/L). Calcium and bicarbonate are typically the predominate cation and anion. Water quality of the Madison Formation is not yet known, but is expected to have a calculated dissolved-solids concentration of about 1,000 mg/L.

Future work will focus first on defining the characteristics and availability of water in the alluvium. Shallow seismic exploration and monitor-well installations will be utilized. Depending on the availability of funding, a major benefit of this study could be the identification of the hydrologic relationship between the Madison Formation and the shallow aquifer system.

Sources of Funds and Support

Montana Bureau of Mines and Geology Appropriated funds matched supplemental funds from:

1. U.S. Department of Interior, Bureau of Indian Affairs

Mobility of Agricultural Chemicals in Montana
Soils and Shallow Aquifers

by

Brian J. Harrison

and

Marvin R. Miller

An evaluation of the mobility of chlorosulfuron (GLEAN) in Montana soils and shallow aquifers has been ongoing since 1988. The objectives of this study were:

To substantiate whether chlorosulfuran is being leached below the rooting depth of Montana crops and into shallow groundwater aquifers; and

If so, can the movement of chlorosulfuron be described in a predictive manner.

Three field plots were instrumented at each of 2 different locations in south-central Montana (Figure 1). The field plots were established at the Southern Agricultural Experiment Station in Huntley, and at the Post Agricultural Experiment Station outside Bozeman. The locations were chosen to allow the evaluation of chlorosulfuron mobility under different climatic and soil regimes.

Each field plot was instrumented with vacuum lysimeters, tensiometers, and neutron access tubes. Monitoring wells were established at the perimeters of both field-plot complexes to monitor the potential for ground water contamination from migration of chlorosulfuron through the unsaturated zone.

Each plot consisted of 5 vacuum lysimeters installed to depths of 6, 12, 24, 36, and 60 inches below ground surface. Tensiometers were installed at depths of 6, 12, 24, and 48 inches below ground surface. Two neutron access tubes were installed to a depth of 10 feet in each plot.

Five monitoring wells were installed at the Huntley site. Dark grey shale was encountered there at depths between 30 and 35 feet below ground surface. One well was located upgradient of the 3 plots, one well was located in the center plot and the final 3 wells were located downgradient of the 3 plots.

Three monitoring wells were installed at the Bozeman site. These wells were drilled to total depths of between 40 and 60 feet below the ground surface. Each was terminated in a thick, dry gravel layer. In each borehole, hollow-stem augers were unable to penetrate beyond 5 feet into this gravel layer. Iron-oxide mottling on the gravels suggested historical water table fluctuations into this gravel zone.

Soil moisture and matric-potential measurements began at the Huntley site in June 1988. Unsaturated zone monitoring continued weekly between June 1 and August 1, 1988. Unsaturated zone monitoring occurred biweekly in August and September 1988. Unsaturated zone monitoring at the Bozeman site occurred on a weekly schedule between July 1 and September 1, 1988.

Ground-water-level measurements were made weekly from Huntley site monitoring wells between June 1 and August 1, 1988. Ground-water monitoring occurred biweekly from August 1 to October 1, 1988. Monitoring wells at the Bozeman site were measured weekly from July 1 to September 1, 1989.

Soil-solution samples were collected on 5 occasions at Huntley site and on 3 occasions at the Bozeman site. Chlorosulfuron was identified in 9 of 32 samples from the test plots on the Southern Agricultural Experiment Station. Chlorosulfuron was detected in 12 of 16 samples collected from the test plots at the Post Agricultural Experiment Station. The highest measured chlorosulfuron concentrations were 21 and 15 micrograms per liter (u/L) at the Post Agricultural Experiment Station. Chlorosulfuron did not exceed 2.10 ug/L in soil solution samples the from test plots at the Southern Agricultural Experiment Station. Chlorosulfuron residues in the fall of 1988 were present at concentrations less than 18 ug/L in soils from the test plots at both Agricultural Experiment Stations.

Ground-water quality samples were collected twice at the Huntley site, once prior to herbicide application, and again at the conclusion of the field monitoring season (September 15, 1989). Chlorosulfuron was not identified in any of the ground-water samples collected from the Huntley site. Ground-water samples could not be collected from the Bozeman site as monitoring wells were bottomed above the water table due to drilling refusal in tight gravels.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

Montana Department of Natural Resources and Conservation - Water Development Grants Program

Evaluation of Porous-Cup Lysimeters in Collecting Representative Concentrations of Anionic Species from Soil Solutions

by

Brian Harrison

and

John L. Sonderegger

The importance of the role the unsaturated zone plays in transport and immobilization of hazardous constituents has lead to increased use of porous-cup lysimeters for collection of soil solution samples. Exclusion of phosphate anions by ceramic porous-cup lysimeters has been reported, but poorly documented, in the soils literature. The objective of this study was to evaluate the potential for exclusion of organic anions by ceramic porous-cup lysimeters.

A series of four artificial soil profiles were constructed in 15-gallon polyethylene test chambers. Each soil profile consisted of washed 10/20 silica sand packed to a bulk density of 1.48 grams per cubic centimeter. A glass sampling well was installed in each soil test chamber to a depth 6 inches above the bottom of the artificial soil profile.

One porous-cup lysimeter was installed in each of the test chambers at a depth 3 feet above the bottom of the soil profile. Both ceramic and Teflon porous-cup lysimeters were used to evaluate the potential for exclusion of anionic herbicides. Lysimeter configuration in each of the test chambers was as follows:

One ceramic porous-cup lysimeter without silica flour pack;
One ceramic porous-cup lysimeter with silica flour pack;
One teflon porous-cup lysimeter without silica flour pack; and
One teflon porous-cup lysimeter with silica flour pack.

Stock solution of a known chlorosulfuron concentration was added to each soil profile. Chlorosulfuron stock solution consisted of deionized water with chlorosulfuron at a concentration of approximately 100 micrograms per liter. Stock solution was added until a 2-foot thick saturated zone was present at the bottom of the test chamber. Vacuum was applied to the lysimeters and soil solution samples collected. Alternating pore volumes were submitted for chlorosulfuron analysis. Samples were collected from the saturated zone, approximately 12 inches below the porous cups, and submitted for chlorosulfuron analysis.

Results from two separate chlorosulfuron analytical events indicate the following:

Chlorosulfuron concentrations in initial samples collected from ceramic porous-cup lysimeters without silica pack exceeded both stock solution and saturated zone concentrations by a factor from 3 to 5. A normalized plot of chlorosulfuron concentration in lysimeter samples versus saturated zone chlorosulfuron concentrations exhibits a generally increasing trend from cup volumes 1 through 5 (Figure 4).

Chlorosulfuron concentrations in initial samples from ceramic porous-cup lysimeters with silica flour pack exceeded chlorosulfuron concentrations in both stock solution and saturated zone samples by factors from 2.5 to 4. However, a normalized plot of lysimeter chlorosulfuron concentration versus saturated zone chlorosulfuron concentration shows a decreasing trend in cup volumes 1 to 5 (Figure 1).

Normalized plots of lysimeter chlorosulfuron concentrations versus saturated zone chlorosulfuron concentrations show decreasing trends for cup volumes 6 through 10 in both ceramic lysimeter test cells.

Soil solution samples could not be collected from Teflon porous-cup lysimeters either with or without silica flour pack. Soil solution samples could not be collected from Teflon lysimeters even after complete saturation of the test cells.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

Montana Water Resources Center, Grant no. 290835, MSU, Bozeman

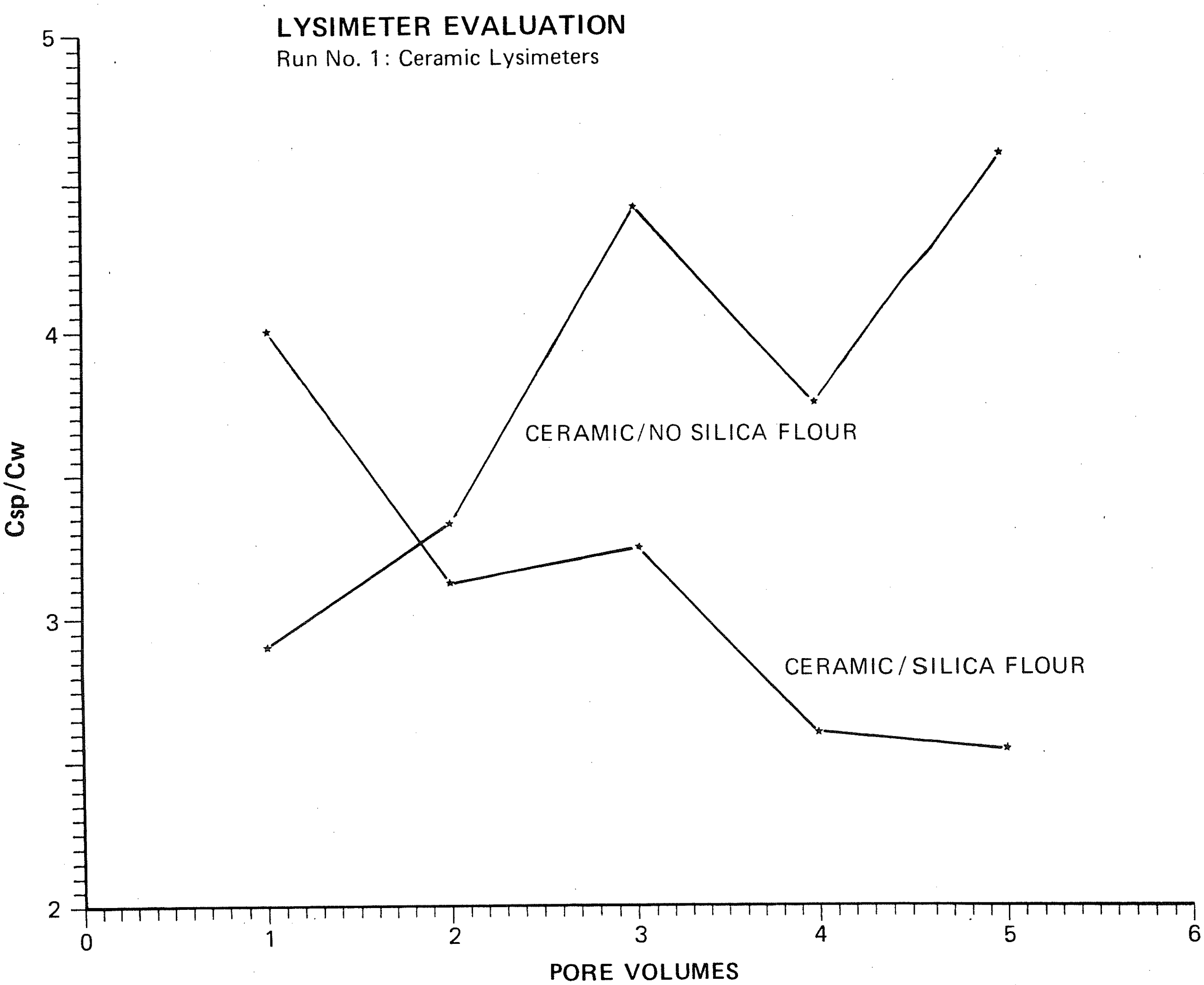


Figure 4. Comparison of lysimeter effectiveness with, and without, silica flour packing.

Evaluation of Porous-Cup Lysimeter Performance at a Hazardous Waste Land Treatment Facility

by

Brian J. Harrison

and

Marvin R. Miller

Appropriate monitoring of waste degradation and immobilization includes collection of soil solution samples through both soil core sampling and porous-cup lysimeter. Soil solution sampling via lysimeters is commonly part of the monitoring requirements contained within a Resource Conservation and Recovery Act (RCRA) Part B Permit. However, previous difficulties in collection of samples from porous-cup lysimeters at the Conoco Landfarm led to concern as to the applicability of these soil solution samplers in the semi-arid Montana climate. This concern prompted the Solid and Hazardous Waste Bureau of the Montana Department of Health and Environmental Sciences (MDHES) to suggest an evaluation of lysimeter efficiency in the Hazardous Waste Land Treatment (HWLT) environment. Conoco Billings Refinery supported the MBMG for the establishment and instrumentation of test plots at the Conoco Billings HWLT Facility for evaluation of lysimeter performance.

Three specific objectives of this field lysimeter evaluation were:

Determination of the ability of porous-cup lysimeters to collect sufficient volumes of soil-pore liquids to meet semiannual sampling requirements;

determination of the appropriate timing for sample collection, providing that porous-cup lysimeters are appropriate for soil solution sampling; and

assessment of the integrity of lysimeter installations within active waste application areas.

Two separate 10-foot square test cells were constructed at the Conoco HWLT Unit. The western or upper test cell was located in the northeast corner of Area V-South and the eastern or lower test cell was located immediately east of Area III. Each cell was constructed with native soils and isolated from surrounding areas by wooden 2-inch by 10-inch framing.

Ceramic porous-cup lysimeters were installed at depths 12 inches, 36 inches, and 66 inches below ground surface in each test cell. In addition, Teflon porous-cup lysimeters were paired with ceramic lysimeters at the 12- and 36-inch depths in each test cell.

A 6-inch lineal thickness of silica-flour slurry was emplaced within each borehole. Bentonite was emplaced in a 2-inch rise immediately above the 6-inch silica flour slurry zone. The remaining borehole annulus was backfilled to within 3 inches of ground surface with cuttings taken from the borehole. The soil cuttings were compacted in 2-inch thick lifts. A 0.5-inch-thick zone of lithium bromide was placed in the borehole at a depth of 2 inches below ground surface. The upper 1.5 inches of borehole annulus were backfilled with bentonite crumbles. The lithium bromide was intended as a tracer to allow evaluation of lysimeter installation integrity.

To allow for soil moisture monitoring over the entire evaluated soil depth, two neutron-probe access tubes and three tensiometers were installed within each test cell. The 1.5-inch ID aluminum neutron-probe access tubes were installed to a depth of 10 feet. Ceramic-tipped tensiometers were emplaced in each test cell at depths of 12 inches, 36 inches, and 66 inches. Soil Moisture Corporation tensiometers in the lower test cell were equipped with a water reservoir and Bourden pressure gauge capable of measuring matric potential to 150 centibars of vacuum. Each tensiometer installed in the upper test cell consisted of ceramic-tipped polyvinylchloride fitted with a rubber septum at the terminus. A Soil Measurement Systems pressure transducer was used to measure soil matric potential in millibars of vacuum.

A soil-moisture monitoring program was designed and implemented to evaluate cumulative annual soil-moisture flux and temporal variations in soil-moisture flux. Spatial and temporal variation in both moisture content and matric potential were monitored to determine the feasibility and/or appropriate timing for soil solution sampling at the HWLT site.

Soil solution sampling was attempted on the first of each month, April through October. However, based on operational limitations of lysimeters and decreased soil moisture mobility at low soil pressure potentials, attempts to sample soil solutions with the porous-cup lysimeters were not made when soil matric potential was below-500 millibars of tension.

Based on soil moisture monitoring and attempted soil-solution-sample collection, the following conclusions regarding porous-cup lysimeters operations at the Conoco HWLT Unit were determined:

> Soil moisture flux during most of the evaluation period was upward within the lysimeter test plots. Small soil moisture influxes generally migrated 10 to 14 inches into the upper soils before the wetting front was immobilized. After initial downward migration, soil-moisture-monitoring data suggested that potential gradient reversals occurred and that soil moisture flux was upwards and out of the soil profile.
>
> A mean hydraulic conductivity of $5x10^{-7}$ cm/sec was calculated from in-situ permeability testing at the Conoco Landfarm. The low permeability of the soils exerted a limiting influence on the depth of infiltration reached by precipitation during the evaluation period. Slow infiltration rates and limited infiltration depths allowed evaporative losses to exert a strong control on the annual soil moisture budget at the landfarm site.
>
> Soil solution samples could not be collected from porous-cup lysimeters even when soil pressure potentials were greater than 500 millibars of vacuum. In each attempted sampling event, vacuums were maintained within porous-cup lysimeters in excess of 24 hours with minimal decay in the applied vacuum.
>
> The lack of soil solution volume did not allow adequate assessment of the lysimeter installation integrity. However, the lack of soil solution volume during periods of standing surface water lends indirect support towards the adequate integrity of the lysimeter installations.

The low soil moisture flux and inability of porous-cup lysimeters to collect soil solution samples suggests that the high clay content of the soils, and their low hydraulic conductivities, limit soil moisture and waste flux in landfarm soils. In addition, the implication of saline-seep conditions evidenced throughout the landfarm indicate that the area serves as a local discharge point and that soil moisture fluxes would be expected to be upwards in such a hydrologic regime.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

Conoco, Incorporated

Hole Plugging with Bentonite in Montana

by

John R. Wheaton

The exploration and development of minerals in Montana has utilized rotary drilling for data acquisition for nearly 100 years. Although the intensity of exploration activity has varied with economic trends, the abundance of valuable minerals in Montana dictates that exploration drilling will always be an environmental concern.

Field inspections by state regulators, including the Department of State Lands, and input from experts with numerous years of drilling experience have emphasized the need to document appropriate hole plugging techniques.

Mineral exploration typically involves assessing the subsurface lithology through the use of drill holes. In the coal fields, reserves are inventoried by an intensive pattern of drill holes. Favorable oil well locations are determined through the use of seismic shot holes. Extractable concentrations of uranium and other minerals are also pin-pointed through drill hole studies. The number of holes drilled in any given year varies according to economic factors, but each year there are hundreds. In 1975, E.W. Bond -- MBMG Special Publication 67 -- estimated that the total number of seismic shot holes drilled in Montana "is probably more than a million". If not properly abandoned, these holes: (1) become avenues for mixing of water from different aquifers, possibly resulting in degraded ground-water quality; (2) allow contamination of ground water from surface sources; (3) may adversely impact springs or other surface waters; (4) and may allow the escape of artesian water or natural gas. There is a clear need for documented and published information regarding acceptable methods of preserving quality and quantity of water resources via environmentally sound and economically feasible well completion and hole abandonment methods.

There are several materials including cement, earth fill and bentonitic clay available to plug drill holes. Cement and concrete are often used to plug holes that encounter artesian water or natural gas. Cement is reasonably effective but expensive. Earth fill is rarely used any longer due to inadequate prevention of interaquifer mixing. One of the most commonly used drill hole abandonment mediums is bentonitic clay (sodium bentonite). Bentonite is a highly plastic (capable of being molded or continuously reformed) montmorillonitic clay that swells extensively when wet. Bentonite is a desirable hole-plugging medium because it swells when wet, has a very low permeability, does not break down over time, is nontoxic, has some flowing capabilities and is relatively inexpensive. Conversely, concrete and cement may shrink in the drill hole, may break down over time, possess flowing capabilities only when initially poured and are fairly expensive. Cement products are most effective in stopping highly pressurized flow of water or gas.

The MBMG and the Montana Department of State Lands are jointly investigating the effectiveness of several bentonite hole-plugging techniques. The techniques include:

1) High-grade, dry bentonite chips
2) High-grade, wetted bentonite chips
3) Bentonite slurry, 9 pounds per gallon, 70 second Marsh funnel viscosity
4) Bentonite slurry, maximum weight and viscosity that is pumpable with standard drill rig pumps
5) Low-grade, dry bentonite chips
6) Low-grade, wetted bentonite chips
7) Mixture of high-grade bentonite chips (25%) and gravel (75%)

Preliminary results indicate that the higher solids content of the bentonite chips provides better ground-water protection. Where the drill-hole lithology has a high porosity, the bentonite slurries tend to migrate away from the drill hole. However, effective implacement of the bentonite chips, especially in deep drill holes, can be highly difficult. During 1990, a progressing cavity pump is expected to be developed that may reduce the difficulty.

The early field trials of the project have demonstrated that low grade bentonite chips, which are available in Montana, have swelling and strength characteristics similar to high grade Wyoming bentonite. If this trend is documented in deep drill holes and seismic holes, the Montana bentonite industry can benefit.

Documentation of effective hole plugging techniques through the project will enable regulatory agencies to better protect ground-water resources. Drillers will be able to use hole-plugging techniques that are appropriate to individual situations with more confidence, and landowners should feel less threatened by mineral exploration and other drilling activities.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds from:

1. Montana Department of Natural Resources and Conservation -- Resource Renewable Development Grants Program
2. Montana Department of State Lands

Technical Oversight

at the

Montana Power Company

Transformer Storage Area

Butte, Montana

by

Terence E. Duaime

and

John J. Metesh

The Montana Power Company Operating Center is located at 1701 South Montana Street in Butte, Montana. The area consists of approximately 50 acres and is adjacent to the Montana Pole National Priority List (NPL) Site to the west and the Silver Bow Creek NPL Site to the north. The area is currently used by the MPC for storing electrical transformers and utility poles. In addition to this, the site has been used for over 100 years for several industrial related uses. Potential hazardous wastes include polychlorinated biphenyl (PCB), pentachlorophenol (PCP), solvents, and petroleum hydrocarbons.

Under the provisions of a Task Order Agreement, the Montana Bureau of Mines and Geology (MBMG) conducted technical oversight for the Montana Department of Health and Environmental Sciences (DHES). Emphasis of the oversight was on hydrogeological site characterization, ground-water and soil sampling, and data interpretation. Specific tasks related to the technical oversight included:

- Review of Site History and Characteristics report
- Review of Site Sampling Plan
- Provision of on-site oversight of MPC contractor's site investigation activities which included monitoring well installation and sampling
- Review of Site Screening Inspection Status report and Final report

Seven monitoring wells were installed in October, 1989 at six locations within the study area. Well-logs and a final report on the field activities were submitted to the DHES in January 1990. Subsequently, document review was completed on the Site Screening Investigation-Final Report in May.

Monitoring of ground-water levels is continuing at the site by the MBMG in conjunction with field activities related to the Montana Pole NPL Site and the Butte Mine-flooding Project.

Sources of Funds and Support

All funding is provided under a Task Order Agreement between the DHES and the Montana College of Mineral Science and Technology and its research branch, the MBMG.

Montana Pole National Priority List Site

Technical Assistance

by

Richard A. Appleman

Terence E. Duaime

John J. Metesh

The Montana Pole Treatment National Priority List Site, located in Butte, Montana, has been identified by the U.S. Environmental Protection Agency as a Superfund site as a result of ground-water, surface-water, and soil contamination associated with a timber treatment plant. Although other contaminants such as heavy metals have been identified, the primary concern is the pentachlorophenol (PCP)/diesel-fuel mix (product) used in the wood-treatment process. In addition to small product spills occurring during operations, an explosion and fire in 1969 caused a considerable amount of product to be discharged to the ground surface.

Subsequent to emergency removal action taken by the U.S. Coast Guard in 1985 and 1986, the Montana Department of Health and Environmental Sciences (DHES) began remedial investigation/feasibility study (RI/FS) activities through a Cooperative Agreement with the U.S. EPA. Coincident with this agreement, a Task Order Agreement was established with the Montana College of Mineral Science and Technology (MCMST) and the Montana Bureau of Mines and Geology (MBMG) to conduct Operations and Maintenance (O&M) of the product-recovery system. Previous to this, the MCMST and the MBMG had been under contract with the U.S. EPA and its contractors to provide O&M.

O&M consists primarily of the maintenance of the ground-water/product recovery system, the monitoring of produce seepage recovery along Silver Bow Creek, ground-water/product-level monitoring, and product recovery from wells not influenced by the recovery system. For the period of October 1986 through May 1990, approximately 10,000 gallons of product have been removed from the ground-water. In addition to O&M, two Master's thesis investigations concerned with the Montana Pole Plant site have been completed by graduate students/ employees of Montana Tech. These are: Emulsion Characterization and Demulsification of Wood Treatment Fluid at the Montana Pole NPL Site, 1988, by J.S. McElroy; and Evaluation of the Product (Diesel-PCP Mixture) Bearing Soils at the Montana Pole Plant NPL Site Butte, Montana, 1989, by H.R. Moore. A third such investigation is in progress and is expected to be completed in 1991.

In April of 1990, an Administrative Order On Consent was issued to the Atlantic Richfield Company (ARCO) to begin an RI/FS at the site. Pursuant to this, a second Task Order Agreement between the DHES and the MBMG has been initiated. Under this agreement, the MBMG will provide technical assistance and oversight for RI/FS activities conducted by ARCO's contractor at the Montana Pole Treatment Plant. This will include oversight of ground-water, surface-water, and soil sampling; monitoring-well installation; and document review.

Sources of Funds and Support

All funding is provided under a Task Order Agreement between the DHES and MCMST.

Technical Oversight

for a Remedial Investigation at the

Hart Refinery Site, Missoula, Montana

by

John J. Metesh

The Hart Refinery, which operated from 1924 to 1951, is located in the central portion of the city of Missoula, adjacent to the Clark Fork River. Subsequent site activities included the processing and storage of timber products and disposal of related wastes. Presently, Champion International and the Roman Catholic Church own portions of the site. Previous investigations by the U.S. Environmental Protection Agency have indicated that on-site soils and ground-water are contaminated with petroleum hydrocarbons.

Under the provisions of a Task Order Agreement with the Montana Department of Health and Environmental Sciences (DHES), the Montana Bureau of Mines and Geology (MBMG) is providing technical oversight emphasizing hydrogeologic site characterization. Specific tasks related to this technical oversight include:

- Review of all EPA, DHES, and Champion contractor reports of the Hart Oil Refinery which includes:
  - EPA Site Investigation report
  - Hart Oil Refinery Site Environmental Property Assessment
- Review Hart Oil Refinery Phase II Property Assessment
- Review Ground-Water Investigation Sampling Plan
- Provide on-site oversight of field activities during the drilling and sampling phase of the investigation

Reports will be prepared for the DHES following each document review and at the end of the field investigation. Project completion is expected to be in August 1990.

Sources of Funds and Support

All funding is provided under a Task Order Agreement between the DHES and the Montana College of Mineral Science and Technology and its research branch, the Montana Bureau of Mines and Geology.

Hydrogeologic Controls on Salt Loads in Coal Strip Mine Spoils

by

John J. Metesh

Coal strip-mining is a process by which coal is removed and the spoils-material is deposited behind an advancing pit. As this coal, and subsequently the spoils-material, are often the principal aquifer for the area, the influence of the mine on ground-water flow and water-quality is of particular concern. The objective of this investigation was to compile existing data obtained by mining companies, the Montana Department of State Lands, and the Montana Bureau of Mines and Geology in order to address these concerns.

The most common method of calculating the flow of ground-water to an open pit is to use a series of equations based on a line-sink for the long side of the pit and a circular-sink for the ends of the pit. The calculation of hydraulic head distribution in the vicinity of a linear pit by these methods is generally not accurate. The two sets of equations fail to arrive at the same head value for a common point in the aquifer. In response to this, the first phase of the investigation was to find an alternative method. An equation was developed that utilizes a single equation to predict the drawdown in a well at a given distance from a linear pit. In addition to distance, the equation is based on the hydraulic conductivity of the aquifer material, the discharge rate from the pit, and the length of the pit. A comparison was then made between calculated values using this equation and those calculated by a computer-generated, finite-element model.

The second phase of the investigation was to determine a statistical relationship between the ground-water transmitting capacity of the spoils-materials and water-quality. Existing water-quality and aquifer-test data were obtained for the Decker Mine, the Rosebud Mine, and the Big Sky Mine. A statistical analysis of the total dissolved solids and transmissivity data for each mine was conducted. After performing several data transformations, the available data indicated little or no correlation between the two parameters. Subsequent comparisons of data from all three mines indicated the same lack of correlation between transmissivity and TDS.

Sources of Funds and Support

Funding for this project was obtained from the Montana University System - Water Resources Research Center.

Hydrogeologic Overview

Parrot Bench and Summit Valley Uranium Prospects

by

John Metesh and Wayne Van Voast

The Montana Bureau of Mines and Geology (MBMG) through a request by the Montana Department of State Lands entered into a contract agreement with Exxon Coal and Mineral Company (ECMC) to provide a hydrogeologic overview of Exxon's Parrot Bench uranium prospect in Jefferson County and their Summit Valley uranium prospect in Madison County. During 1979 and 1980, ECMC conducted uranium exploration drilling programs in these areas under prospecting licenses granted by the Department of State Lands. Emphasis was placed on Eocene and Miocene age alluvial fan deposits and fluvial-lacustrine deposits adjacent to the Tobacco Root Mountains. There were 15 exploration holes drilled in the Parrot Bench area and 30 in the Summit Valley area, ranging in depth to as much as 2000 feet.

The purpose of the MBMG hydrogeologic investigation was to review information from exploration-hole logs and borehole geophysics supplied by ECMC, to evaluate all other available geologic and hydrologic data, and to estimate the potential for ground-water contamination resulting from inadequately-plugged drill holes. An inventory of water-well logs and water-quality data for each prospect area was conducted and a hydrogeologic evaluation was made.

It was determined that a strong potential for mixing of waters from several aquifers exists in both prospect areas. For the case of the Parrot Bench alluvial fan, un-plugged boreholes have the potential to connect confined and semi-confined ground-water systems. Surface-water near the apex of the fan has a potential of being intercepted and re-routed to a deeper system by un-plugged boreholes.

Summit Valley is an area where agricultural activity and the potential for surface-water - ground-water mixing warrants particular concern. In addition to this, the locations of many of the boreholes in relation to highway and railroad borrow pits increases the possibility that aquifers can be contaminated by surface water via unplugged boreholes.

Sources of Funds and Support

Funding was provided for under a contract agreement with Exxon Coal and Minerals Company.

Reclamation Techniques for Heavy Metal Contaminated Agricultural Lands in Deer Lodge, Powell, and Silver Bow Counties

by

John L. Sonderegger

There has been a concern that the use of soil amendments to improve plant growth in tailings-damaged soils would release metals into the environment both through vegetation and as soil water which would migrate to shallow aquifers. To evaluate the effect of soils reclamation, test studies were conducted on the Spangler Ranch in the southern Deer Lodge Valley. Vegetative studies were conducted by Schafer and Associates (1988). This is follow-up study to evaluate the reproductivity of laboratory bench tests run in conjunction with field sampling of the vadose (unsaturated) zone water under different field-plot conditions. The major concern was that the release of arsenic under more alkaline conditions typical of the amended soils would increase, causing degradation of both ground- and surface-water quality.

A study of soil-amendment effects upon soil-water chemistry and the mobility of several metals and arsenic in tailings-damaged soils was conducted by the Montana Bureau of Mines and Geology. Results of the previous study had shown differential results between bench studies conducted using saturated leaching columns and field samples collected using lysimeters at test plot. Additionally, pH values of leachate solutions from the column containing untreated soils in the laboratory experiments were not acidic, whereas the field samples all showed acid pH values in the early samples, and only late in the study did the field pH values for limes (L) and limed-with-phosphate (L+P) soils become alkaline.

The laboratory experiments were re-run using newly acquired soil samples from the test site, at the request of the Department of Natural Resources and Conservation. The sampled material was tested for soil-slurry pH in the field to assure that the soils to be used were representative of the tailings-damaged soils at that site. Field slurry values ranged from 4.5 to 4.9 for the materials used in the replication experiments.

The results confirm the basic pattern of relative metal mobility determined in the earlier study. The arsenic release rates after approximately 100 pore volumes of leachate ranged from 19 to 22 micrograms per gram. The unamended-soil leachate pH never became alkaline. Both amended-soil leachates, while initially yielding acid pH values, had alkaline values after about two pore volumes had passed through the columns.

The lime-only amendment is recommended for reclamation purposes in the project's final report (MBMG Open-File Report No. 230), completed in June, 1990. The most practical aspect of this research is the verification that the agricultural lime amendment is the more effective method of increasing soil pH while not causing enhanced release of arsenic from the contaminated soils. The use of extracts or partial digestion techniques in evaluating trace-metal transport can be misleading and is not recommended. It is recommended that "whole rock analysis" be run and that the trace-element data be used in conjunction with aqua regia digest results.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

1. Montana Department of Natural Resources and Conservation - Resource Indemnity Trust program.
2. Mile High Conservation District, Butte.

Evaluation of Agricultural Chemical Contamination of Groundwater

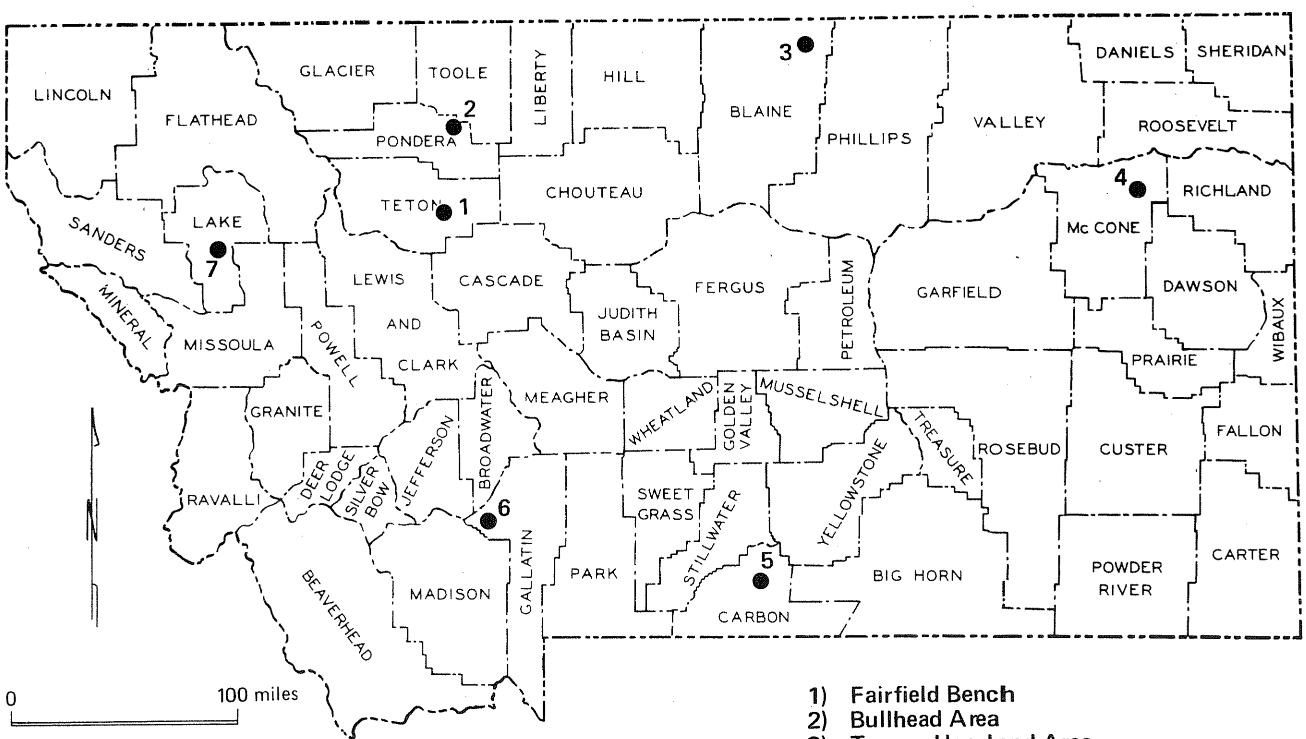
by

Kathleen Miller

The Montana Bureau of Mines and Geology, Hydrology Division has cooperatively developed two programs for the evaluation of agricultural chemical contamination of State ground waters.

Montana House Bill 757 established an agricultural-chemical ground-water protection program to be administered by the Department of Agriculture and the Department of Health in cooperation with other agencies. The Department of Agriculture and the Montana Bureau of Mines and Geology are to cooperatively prioritize the collection of necessary data on selected aquifers for submission to the Department of Health and Environmental Sciences for classification of ground water.

Establishment of a monitoring network to help assess the extent of agricultural chemicals in Montana's ground-water resource is the mission of the second project. The goals of this project are to establish six to seven sites statewide (Figure 5) that will serve as a long-term (20 years) monitoring network to observe changes and trends in pesticide contamination of ground water that may occur with changes in management practices and chemical usage. This project will identify those management practices and agrichemicals which have the greatest potential for compromising ground-water quality in Montana. The soils and hydrogeology at each site will be characterized in some detail to provide a better overall understanding of the potential for pesticide movement in a number of hydrogeologic terrains common to the State. In addition, since a large portion of the annual ground-water recharge in Montana occurs with spring precipitation events, nitrate and pesticide movement through the unsaturated zone into the water table will be monitored over two spring seasons to assess the potential for the use of nitrate movement as an indication of pesticide movement. The completion of this project will be accomplished through a cooperative effort of the Montana Department of Agriculture, MBMG, and the MSU Plant and Soils Department. The Montana Bureau of Mines and Geology will provide the hydrogeologic characterization of each monitoring site, the evaluation of the potential for use of nitrate as an



1) Fairfield Bench
2) Bullhead Area
3) Turner-Hoagland Area
4) Vida Area
5) Edgar Area
6) Amsterdam-Manhattan Area
7) Ronan Area

Figure 5. Locations of proposed permanent groundwater observation wells.

indicator of pesticide flux, and a share of the responsibility for sample collection.

The permanent monitoring wells have been located in areas that represent a cross section of crops and cropping practices within Montana. More importantly, each site occurs over shallow aquifers which are relatively vulnerable to ag-chemical contamination. The types of crops produced include irrigated small grains, dryland small grains, sugarbeets, and potatoes. The sites that have been selected for the project are identified in (Figure 1).

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

1. Legislative appropriation, HB 757 (1989 Legislature)
2. Department of Natural Resources and Conservation; Water Development and Renewable Resource Development Program

Turner-Hogeland Artificial Recharge Demonstration Site

by

Thomas W. Patton

In November 1989 the Montana Bureau of Mines and Geology in cooperation with the U.S. Bureau of Reclamation began construction of an artificial recharge demonstration site in northern Blain County. The project is in it first field season and only preliminary information regarding the geology and water levels under the site are available. Much additional information will be gathered during the winter of 1990-1991 when the site enters its first major data-collection season. The goal of the project is to determine if snow entrapment on recharge zones to a shallow aquifer can enhance the amount of recharge to the aquifer.

The recharge study will examine total recharge to the Turner-Hogeland aquifer but will concentrate on winter-time recharge derived from snowmelt. The demonstration site will consist of two parts (Figure 6). The northern part will be the recharge site where tall wheatgrass barriers will be planted between cropping strips in a crop-fallow field. To enhance the snow-catching ability of the site the cropping strips will be approximately 60 feet in width. The wheatgrass barriers will act as snow-accumulation devices to trap snow on the recharge site. Meltwater from the snow will be allowed to infiltrate the land surface, and when the infiltration has passed the root zone, it well be considered recharge.

Monitoring wells will be drilled to monitor the water table under the site and to check water quality up-gradient, under, and downgradient from the site. Water in the unsaturated zone will be monitored through the use of a neutron probe. Precipitation, temperature, wind speed, wind direction, and evaporation will be monitored by appropriate equipment installed at the site. Snow water content will be measured by coring and weighing known volumes of snow at the site. A local observer will be hired by the Blaine County Conservation District in cooperation with the Montana Bureau of Mines and Geology to operate the field equipment and to make timely observations of climate, snow water content, and monitoring-well water levels.

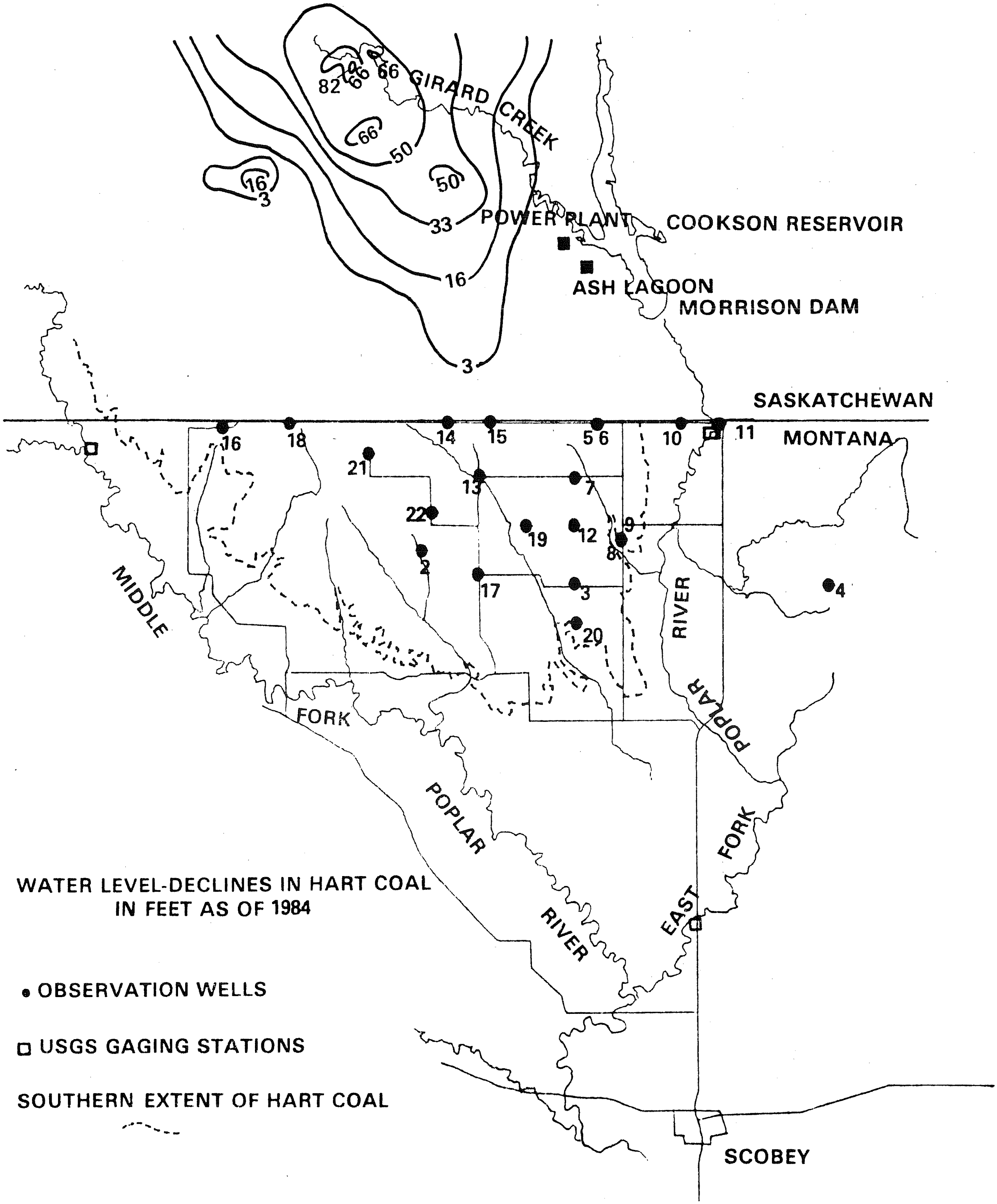


Figure 6. Site plan for the Turner-Hogeland artificial recharge demonstration site.

The southern part of the site will be the control for the recharge experiments. The control site will be treated exactly the same as the recharge site but will not utilize wheatgrass barriers to trap snow. The control portion of the site will undergo normal crop-fallow farming with strips 120 feet in width. A set of monitoring wells similar to those drilled on the recharge part of the demonstration site will be drilled.

To date, six observation wells have been drilled around the perimeter of the site and one well up-gradient. The wells have been developed and good communication between the wells and the aquifer has been established. Land-surface and casing-top elevations have been leveled in and two measurements of the water table have been completed. Ground water flows across the site from southwest to northeast with a total fall in head of approximately 4 feet. The water table ranges between 19 and 24 feet below land surface, depth to depth to bedrock under the aquifer ranges from 30 to 49 feet below land surface.

The Turner-Hogeland demonstration site will operate for the next 5 winter seasons collecting information about the relationship between snow accumulation on the land surface and recharge to the Turner-Hogeland aquifer.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

1. U.S. Bureau of Reclamation

Ground Water Information Center

Data Base

by

Thomas W. Patton

Water-well log and water-quality data bases at the Montana Bureau of Mines and Geology Ground Water Information Center (GWIC) were greatly improved during the last biennium under funding from the Resource Indemnity Trust (RIT) Program and from the Environmental Protection Agency (EPA). The first of two RIT grants provided support for personnel to finish moving the data bases from the Montana Tech computer system to the Montana Bureau of Mines and Geology Prime minicomputer, and to continue updating, verification, and addition of new data. The second RIT grant is providing resources to add historic information about water quality in Montana's deep aquifers and to create a data base for deep aquifer information found in Montana's oil and gas well records. An EPA grant provided assistance in improving the links between the GWIC and microcomputers, and in entry of some historic water quality information for the Judith River and Kootenai Formations. Under the Deep Aquifer RIT grant, 298 new analyses have been added to the data system. Under the EPA grant, 362 analyses were added.

Currently, 102,000 water-well appropriations and water-well logs are contained in the well-log data base and 9,845 water-quality analyses are in the water-quality data base. The water-quality analyses represent approximately 6,200 wells obtaining water from many different aquifers in Montana.

Prior to the original RIT grant and its companion Water Development Grant (which provided the computer hardware and software languages for the GWIC) the well-log information was scattered in 56 separate files. Approximately one 4-drawer file cabinet of well logs waited processing, and software to access any of the information previously placed in the system was not available. None of the information that had been keystroked into the computer system had been office verified for accuracy. Retrieval of information was strictly by hand involving locating the paper well log(s) and reporting the desired information to the requester, most often by photocopying the entire well log and sending it to the individual. Requests for well-log information for large geographic areas required many man-hours to service and resulted in much wear and tear on the paper files or required the construction of specialized programs on the computer. Water-quality information was in somewhat better shape with all of the information complied into one file and an initial program constructed to access the data, but it still required special programs for many types of access.

Presently, the water-well log information is available interactively on the Prime minicomputer for the entire state and is used by the GWIC daily to answer requests for information. Location searches and county-wide searches are most common, but the person conducting the search has other options of searching by owner name, well depth, well yield, geologic source, year drilled, and water use. Information can be provided to the user in several forms. The information may be presented on the computer screen, or may be made into several types of reports. Printed listings of the water-well records containing information about total depth, static water level, pumping water level, yield, owner name, and so forth are available and can be mailed to outside users. The well information is also available on magnetic media as ASCII standard data format files or as data-base format files compatible with Dbase III and its companion microprocessor based data-base management systems.

The availability of alternative forms for shipping large masses of information to those who request it has greatly reduced physical wear and tear on the paper well-log files. Typically, users request a printout or disk containing the information for their area of interest, review the information, and then select well-logs which are of most value to them. Photocopies of the selected logs may then be made and sent to the user. The newer procedures have created savings in the amount of time it takes to service requests for well-log information and has reduced the number of well log photocopies produced at the GWIC.

Water-quality information has been transferred to the Prime Information data base manager on the minicomputer. The new data-base manager allows field-by-field retrievals of water-quality information, and allows the user to select analyses of interest based on many types of criteria. For example, types of retrievals such as: *"List all water-quality data for sites in Flathead County that are from wells that have dissolved solids of more than 500 milligrams per liter."* are now possible without the construction of a special-purpose program. The data-base manager also will allow simplification of the water-quality file by consolidation of all analyses for a site under one site record, no longer requiring that each analysis have an individual site record. The consolidation should save considerable disk storage space in the water-quality file. GWIC personnel are not verifying information in the water-quality data base and are deleting site information that is no longer required by the data base.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

1. U.S. Environmental Protection Agency
2. Montana Department of Natural Resources and Conservation - Resources Indemnity Trust Program

Poplar River Project

by

Fred A. Schmidt and Brenda C. Sholes

The Poplar River, including the East and West Forks, drains south from Canada and into the Missouri River at Poplar, Montana. The river system occupies a drainage of about 3,300 square miles with roughly two thirds of the area within the United States (Figure 7).

In 1972, Saskatchewan Power Corporation requested 6,000 acre-feet of water annually from the flow of the East Poplar River. Two years later they announced plans to build a coal-fired generating plant about 5 miles north of the International Boundary. The Province of Saskatchewan gave permission to construct Morrison Dam and the 33,000 acre-foot Cookson Reservoir. In the meantime, the Poplar River Task Force of the Souris-Red River Board was formed to address water apportionment between the United States and Canada. Recommendations for apportionment were made to the International Joint Commission in 1976.

The mining of coal began in 1980, and the first of two 300-megawatt generating plants went on line in June 1981. The second unit was in operation near the end of 1983. During the construction phase of the facilities in 1977, an International Water Quality Board had been established to deal with potential water-quality problems, both surface and ground water. The Board recognized that serious problems could result from the operation of the power plant and associated activities, including the mining of nearby coal. Recommendations were made by the Board as to monitoring activities that should take place in Canada and the United States. A Bilateral Monitoring Committee was later established to direct and coordinate the monitoring.

Two surface-water sites in the United States have been utilized as principal sampling stations: (1) East Poplar River at the International Boundary and (2) Poplar River at the International Boundary. The East Poplar River at the International Boundary also is a Canadian sampling station. Water samples are collected approximately monthly and are analyzed for a variety of constituents, most of which fall into categories of major ions, nutrients, trace elements and various field parameters. Daily samples for analyses of specific

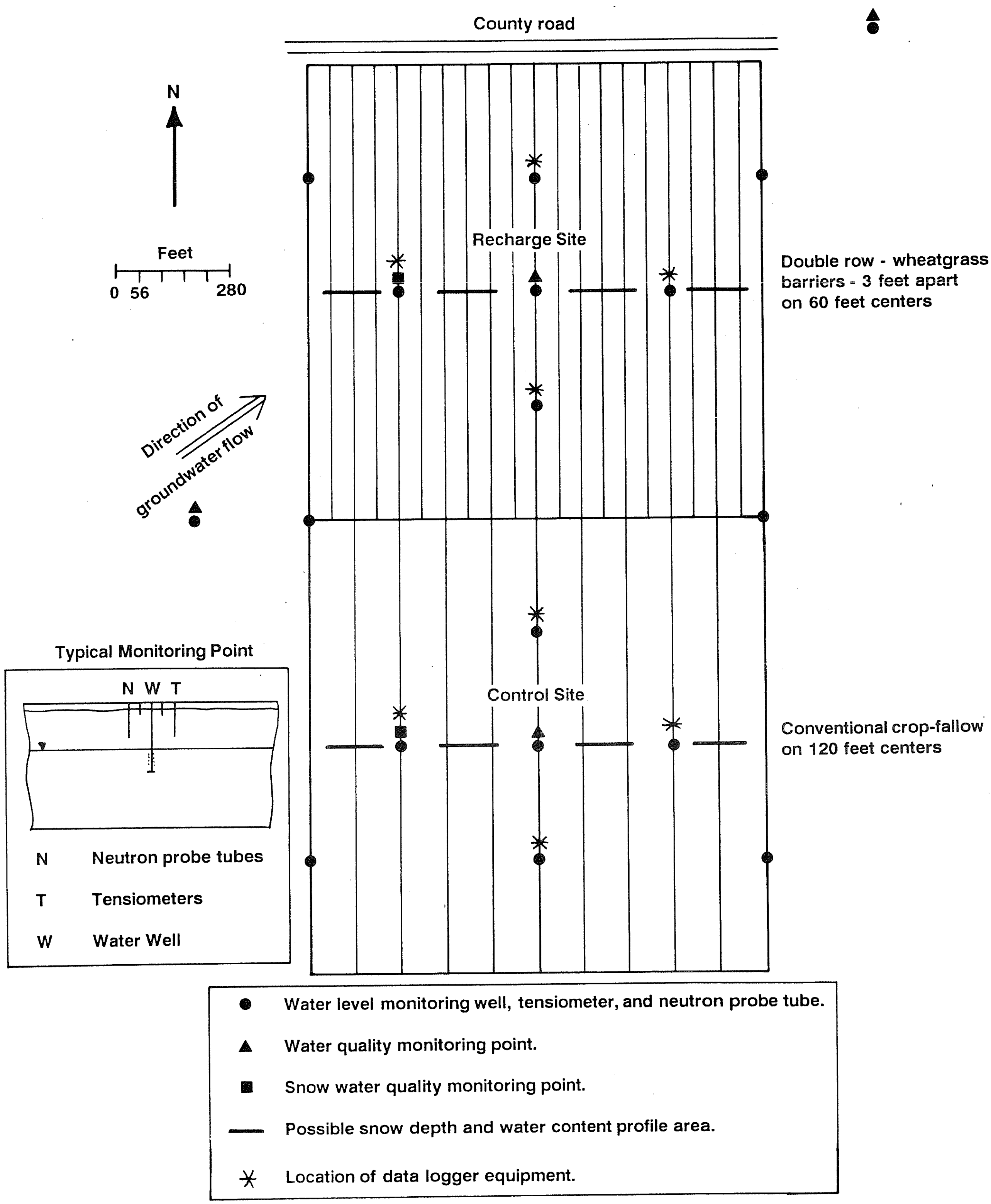


Figure 7. Monitering network on U.S. side of the border, and water-level declines and power-plant facilities on Canadian side of the border in Poplar River drainage.

conductance are collected from the East Poplar River at the International Boundary. Data from the monitoring program are compiled quarterly and are examined and exchanged between countries. Annually, the data are interpreted by the Bilateral Monitoring Committee, and a report is sent to State, Provincial and Federal governments.

To evaluate the potential impact of mine dewatering on adjacent aquifers, numerous observation wells have been installed; 20 of these are placed south of the International Boundary (Figure 7). These 20 wells are maintained by the Montana Bureau of Mines and Geology. Work consists of water-level monitoring, pumping for samples, and report preparation. Particular attention is devoted to ground-water mounding related to Cookson Reservoir, to water-level declines resulting from mining, and to changes in ground-water quality.

The monitoring to date has delineated water-level declines around the mine; however, no significant changes to ground-water quality or quantity have been detected south of the border in Montana.

Conditions which have the potential to affect Montana are the continuing drought in the area and ground-water pumping to alleviate saline seep problems. The water level in Cookson Reservoir is substantially lower due to the drought. This increases the potential for higher concentrations of dissolved solids in the reservoir. Water from the reservoir is released at selected times to meet apportionment agreements. The ground-water pumping is approximately two miles north of the border along the East Fork of the Poplar River. Ground-water flow into Montana would then be affected, dependent upon the extent of dewatering.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds and support from:

1. Montana Department of Natural Resources and Conservation - Water Development Bureau (Grants Program)
2. Montana Coal Board
3. Daniels County Conservation District
4. International Joint Commission, Poplar River Water Quality Committee

Impacts on Water Quality From Plow-Out and Saline-Seep Reclamation Practices, Stillwater County, Montana

by

Terence E. Duaime

The Stillwater Conservation District (SCD) and the U.S. Department of Agriculture-Soil Conservation Service (SCS) initiated a 10-year saline-seep demonstration project during the fall of 1983. The project area is in Stillwater County at the Herzog-Zinne Farm site. The purpose of this demonstration project is to apply previously successful saline-seep reclamation practices from the Hi-Line and north central area of Montana, to areas affected with saline-seep in south central Montana. Through the efforts and involvement of numerous parties, work began at this site in November 1983. Initial work consisted of drilling and installing monitoring wells. Additional wells were drilled and a base map of the site was constructed indicating the location and elevation of monitoring wells during 1984. Additional wells were installed within an area of the site where native sod was recently broken (plow-out) and planted during the fall of 1985.

Water-level measurements of wells are taken yearly from late March through October, while water-quality samples are collected from selected wells periodically. In addition to well-water quality sampling, sampling has occurred at lysimeter (soil water) sites, which were established adjacent to five monitoring wells within the demonstration site. In general, ground-water quality is poor to very poor throughout this site and degrades from the recharge (northeast) portion to the discharge portion of the site (southwest). The predominant water types are sodium sulfate ($NaSO_4$) and sodium magnesium-sulfate ($NaMgSO_4$), which are typical of saline-seep impacted waters. In a majority of the ground-water samples, concentrations of chemical constituents exceeded the recommended/permissible limits for drinking water established by the U.S. Environmental Protection Agency. Sodium, sulfate, chloride, selenium and occasionally nitrate are the constituents most commonly occurring in high concentrations.

Alfalfa was planted in the southeast and south central portion of the site in order to lower ground-water levels. The levels have dropped more than eight feet where the alfalfa was planted. Alfalfa was not planted in the main recharge area; however, there are plans to seed alfalfa in the upper recharge areas for lowering water levels in the discharge area (southwest) of the site where the spread of seeps has continued.

Sources of Funds and Support

1. Department of Natural Resources and Conservation - Water Development (Grants Program)

Travona Mine Aquifer Test

by

Terence C. Duaime, John J. Metesh,
Marvin R. Miller, and Fred A. Schmidt

The Silver Bow Creek Superfund site is a large,complex site where wastes from mining and associated operations have led to the degradation of surface water and ground water. The Butte Addition - Butte Mine Flooding Operable Unit is the portion of the site dealing with contaminated and potentially-contaminated bedrock ground water. The Travona Aquifer Test was conducted as a monitoring task for this operable unit in an attempt to: 1) document the quantity of water necessary to pump from an area where water levels would need to be stabilized in the near future; and 2) to document the quality of this pumped water for designing a treatment plant for removing contaminants prior to its discharge to Silver Bow Creek.

The Travona mine shaft was pumped continuously for a period of 28 days from January 25, 1989 through February 22, 1989. The volume of water pumped from the mine was 17.3 million gallons, the equivalent of 2.3 million cubic feet or 53 acre feet. Continuous water-level and water-quality monitoring of the discharge water occurred at the Travona Mine. Water-quality samples were collected a minimum of three times daily at the Travona mine, while 24-hour, flow-weighted, composite samples were collected at the Butte-Silver Bow sewage treatment plant, to which the pumped water was piped during this test. Additionally, 15 ground-water monitoring sites were established where water levels were measured continuously with recorders, or weekly with steel tapes or well probes. Pumping rates varied from 203 gallons per minute (gpm) to 726 gpm, which caused 32 feet of water-level drawdown in the Travona mine shaft.

Most water-quality changes were judged insignificant throughout this test. Chemical concentrations that did not exceed standards established under the Safe Drinking Water Act or the Clean Water Act-acute criteria at the start of the test, did not increase to levels exceeding those standards by the end of the test. Manganese, sulfate, lead, zinc and arsenic were the only parameters which showed statistically significant changes throughout the course of the pumping test, when judged by comparing mean concentrations during the initial and final pumping rates. Dissolved manganese, lead, zinc, and arsenic showed concentration decreases between and initial and final pumping rates, while total recoverable zinc concentrations increased for the same period.

Measurements of the sewage-treatment-plant performance were highly variable during the test. At the peak flow rate of 726 gpm, the Travona discharge water represented nearly 20 percent of the flow to the plant. Since the pumping test was short, long-term impacts on the treatment plant cannot be determined. Potential impacts would be higher at higher pumping rates, when Travona discharge water becomes a greater percentage of inflow water.

The major observed impact was the increase in both dissolved and total-recoverable arsenic in the sewage treatment plant effluent. Concentrations ranged from 10.5 to 23 ug/L for dissolved arsenic and from to 11 to 23 ug/L for total recoverable arsenic during various pumping rates, while pre- and post- pumping arsenic concentrations ranged between 3.9 and 3.1 ug/L for the dissolved fraction and 3.9 and 3.3 ug/L for the total-recoverable fraction.

A number of methods, both conventional and non-conventional, were used to quantify the hydrologic characteristics of the bedrock in the Travona mine area. Both drawdown and recovery data were used to aid data reduction and interpretation for determining hydraulic conductivity, transmissivity, and storage coefficient of the system.

It appears that in many cases the recovery data best represent the aquifer under investigation. The effects of variable pump discharge are eliminated, and only natural aquifer-boundary conditions are active. The assumptions of the model chosen best representative of the Travona mine system are that it is an unconfined system subject to a delayed response from both fracture and matrix storage.

Sources of Funds and Support

Funding for this project was provided through a task order with the Montana Department of Health and Environmental Sciences - Solid and Hazardous Waste Bureau, (MDHES-SWB) following provisions outlined in a Memorandum of Agreement between the MDHES-SWB and MBMG.

Montana Water Well Contractors Board Participation

by

Robert Bergantino

and

Wayne Van Voast

By statute, the Montana Bureau of Mines and geology provides one staff member to serve on the Montana Water Well Contractors Board. The Board consists of five members appointed by the governor: two are licensed water-well contractors, the others represent the Department of Natural Resources and Conservation, the Department of Health and Environmental Sciences' Water Quality Bureau, and the Montana Bureau of Mines and Geology. Under mandates by the 1985 and 1987 Legislature, the Board had been charged with writing new rules and standards for the water-well and monitoring-well industries for increased protection of the State's groundwater resource.

New rules and standards for water-well construction were completed by the Board and were approved by the 1987 Legislature. During the 1987-89 biennium, establishment of licensing procedures, rules, and construction standards for monitoring-well installers was an intensive objective of the Board. The Bureau representative until August 1989, Wayne Van Voast, was chairman of a special task force charged with drafting the new standards. The task force, composed of representatives from State and Federal agencies and personnel from the water-well and monitoring-well industries and various service companies, met numerous times across the state.

The task force completed its draft in July, 1988. The draft subsequently was approved by the Board. Following public hearings in September 1988, the new rules and standards were approved by the 1989 Legislature. Robert Bergantino replaced Van Voast on the Board in August, 1989, and has since participated actively in the design of training programs to assure highest possible license ethics, standards, and skills.

Sources of Funds and Support

Montana Bureau of Mines and Geology appropriated funds matched with supplemental funds from:

1. Department of Natural Resources and Conservation
    - Montana Water-Well Contractors Board

ANALYTICAL DIVISION

Scott S. Hughes
Division Chief

The Analytical Division comprises a series of research quality, production-oriented inorganic laboratories for multiple element analyses, and other chemical and physical testing, of nearly all conceivable types of materials. Current applications in the Analytical Division are concentrated on groundwater and surface water samples, while additional operations include analyses of soil, rock, coal and some biologic materials. Chemical analyses of geologic and hydrologic materials are provided as a service to professionals from the Bureau's two primary divisions (Hydrology, and Geology and Mineral Resources), non-private agencies (U.S. Geological Survey, U.S. Forest Service, state and local governments, etc.) and faculty researchers from Montana Tech and other institutions.

The Analytical Division employs two full-time chemists, an accounting technician (half-time), and one to three student laboratory technicians. The two chemists are active in the development of new techniques as well as maintaining research quality analyses during routine or specialized procedures. Student technicians are provided with opportunities to gain laboratory experience and, depending on abilities and interests, are gradually given analytical responsibilities. Upon graduation, most of the student technicians, having gained significant expertise in our laboratories, are offered good positions in private companies.

The Division's performance rating by the U.S. Geological Survey's semiannual Standard Reference Water Sample program has been consistently ranked over the last decade in the high percentiles (normally higher than 90%) of more than 120 participating labs. The Analytical Division maintains a quality control program of duplicate, chemical spike and reference standard analyses commensurate with recommendations by the U.S. Environmental Protection Agency. Performance evaluations are also conducted by the E.P.A. during semiannual testing of prepared solutions. Results are provided to laboratories to provide controls and evaluations of analytical procedures and not as a ranking of performance. Results of U.S.G.S. and E.P.A. reference analyses may be obtained upon request. A compilation of U.S.G.S. performance ratings for the last three years is given in Table 1.

Principal techniques include: [1] inductively coupled plasma (ICP) emission spectroscopy for analyses of 24 major cations and trace elements in water and digested solids, [2] ion chromatography for analyses of anion compounds (e.g. chloride, phosphate, sulphate, etc.), [3] atomic absorption spectrophotometry (including hydride methods) for analyses of specific trace metals such as arsenic, selenium, mercury and antimony. These operations are joined with supportive procedures for measuring many other parameters, such as alkalinity and specific conductivity, on a routine basis. Techniques required for individual research products (e.g. CO_2 in rock samples, fire assays, and BTU in coal) are incorporated as needed. Two additional principal techniques were introduced in Spring of 1990: [1] gas chromatography for organic constituents, such as Total Petroleum Hydrocarbon compounds and BTEX (Benzene, Toluene, Ethylene and Xylene) in soil and water and [2] neutron activation analysis (NAA) for rare earth and other trace elements in rock and soil.

During the FY 1989-90 biennium the Analytical Division provided analyses for 33 grant-supported research projects conducted on the Montana Tech campus. Twenty-four of these projects (primarily hydrology) were undertaken by researchers in the Bureau, whereas the remaining projects were funded by grants to the departments of Environmental Engineering, Metallurgy, and Biology. Currently, more than 1000 water analyses are performed each year (out of 1500^+ total) that are related to the endeavors of the Hydrology Division in the Bureau.

Last year, the Analytical Division initiated a program of providing support for nonfunded or under-funded research projects. Many research projects are not either initiated or completed simply because there is a lack of preliminary analytical data with which to present arguments for extended funding, or additional data beyond the initial request is required. In order to promote research activities on the Montana Tech campus and, therefore, enhance future chances for obtaining research endowments, some analytical work is conducted at or below cost, with the balance being designated as MBMG support. Below are listed projects, since August 1989, related in publications, theses, or other research endeavors that have been supported, entirely or in part, by the Analytical Division. Much of this research could not have been accomplished without the assistance of dedicated personnel and provision of analytical data by the Bureau. This list, which does not include the grant-supported academic projects or projects conducted by government agencies, is intended to provide examples of research supported indirectly by the Montana Bureau of Mines and Geology.

1. Arsenic in Fish Components, Joella Carter, Regional Science Fair, College of Great Falls, William R. Peterson, Director.

2. Silver-Bow Creek -- Upper Clark Fork River Storm Event Monitoring, Ted Duaime, MBMG Hydrology Division, Montana Tech.

3. Biohydrometallurgy and Bioleaching Experiments, Deanna Anderson, Biological Science Dept., Montana Tech.

4. Particle Size Analysis and Heavy Metal Distribution in Mining Waste Dumps, Garrett Byrne, M.S. Thesis under Julie LeFever, Industrial Hygiene Dept., Montana Tech.

5. Agricultural Management of Nitrogen and Heavy Metals on Land Receiving Municipal Sewage Sludge, Margaret Hofacker, Environmental Engineering Dept., Montana Tech.

6. Butte Mine Flooding Monitoring, Ted Duaime, MBMG Hydrology Division, Montana Tech.

7. Chloritic Alteration of Precambrian Metamorphic Rocks, Southern Highland Mountains, Richard Berg, MBMG Geology and Mineral Resources Division, Montana Tech.

8. Comparison of Field Sampling Techniques versus Lab Analysis Using Fe as a Basis, Vivian Drake, student project for John Sonderegger, Geological Engineering Dept., Montana Tech.

9. Aid to Small Miners, Rob McCulloch, MBMG Geology and Mineral Resources Division, Montana Tech.

10. Uncle Sam Gulch Acid Mine Drainage Abatement, Elmer Gless, Biological Science Dept., Montana Tech.

11. Effects of Mine Waters on Living Organisms, Jason Hanni, State Science Fair, Missoula, MT (gold medal winner).

12. Reclamation Techniques for Heavy Metal Contaminated Agricultural Lands in Deerlodge, Powell, and Silver-Bow Counties, John Sonderegger, Geological Engineering Dept., Montana Tech.

Long-term goals and expectations of the Analytical Division are to continue to serve researchers throughout Montana and to strive for excellence in all scientific inquiries that utilize analytical data. An extended exposure within the overall development of research capabilities in the Montana system of higher education, including acquisition of new state-of-the-art equipment and attainment of substantial federal research grants, is the primary directive of this laboratory. It is expected that our progress, currently being judged by the quantity and quality of chemical analyses, will eventually be judged on the basis of active involvement in research in environmental sciences, high-tech materials, hydrologic and geologic resource assessments, and broad problems relating to geoscience.

Table 1. U.S. Geological Survey Water Reference Samples.

MBMG Analytical Division National Ratings

4 = Excellent 1 = Questionable
3 = Good 0 = Poor
2 = Satisfactory

Date	Sample	Average Rating	Rank*	Total # Labs	Percentile (% Below)
			Major Elements		
1/87	M-96	3.69	4	123	97
6/87	M-98	3.47	9	132	93
6/87	M-100	3.75	5	132	96
12/87	M-102	3.07	34	137	75
8/88	M-104	3.33	25	148	83
1/89	M-106	3.38	27	148	82
8/89	M-110	3.33	12	131	91
			Trace Elements		
1/87	T-97	3.75	4	120	97
6/87	T-99	3.50	6	132	95
12/87	T-101	3.84	1	137	100
8/88	T-103	3.76	2	148	98
1/89	T-105	3.79	1	139	100
8/89	T-107	3.13	7	135	95
	Nutrients		No. of constituents reported		
1/87	N-17	4.00		3 of 6	
6/87	N-18	4.00		2 of 6	
12/87	N-19	3.33		4 of 6	
8/88	N-20	2.67		3 of 6	
1/89	N-21	3.00		3 of 6	
8/89	N-22	2.00		2 of 6	
8/89	N-23	4.00		2 of 6	

*Based on labs reporting a minimum number of constituent elements: Majors = 10 of 17, Traces = 20 of 26, Nutrients = 4 of 6.

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