Annual Report **2016-2017**

Executive Summary

Throughout the world, geological survey agencies mandated by government maintain the systematic subsurface information that is needed for government and society to function optimally. As with other federal systems, the US has a federal survey – the US Geological Survey (USGS) which has a budget of >$1B and ~10,000 employees – and state geological surveys that presently receive total annual funding of $230M, and have over 1950 employees. The Minnesota Geological Survey (MGS), established as part of the University of Minnesota in 1872, has been located at 2609 West Territorial Road in St Paul since 2015, and has a budget of ~$3M/year and a staff of ~40 that has grown by 50% and stabilized over the past decade. Current MGS focus is on the goals of Legislative water resource planning that specifies the need for statewide completion with a decade or so, accompanied and followed by updating, of multi-layered County Geologic Atlases constructed in partnership with MN Department of Natural Resources (DNR) and with Counties; there is concurrent focus on the research, databases, outreach, and statewide mapping needed to optimize the Atlases.

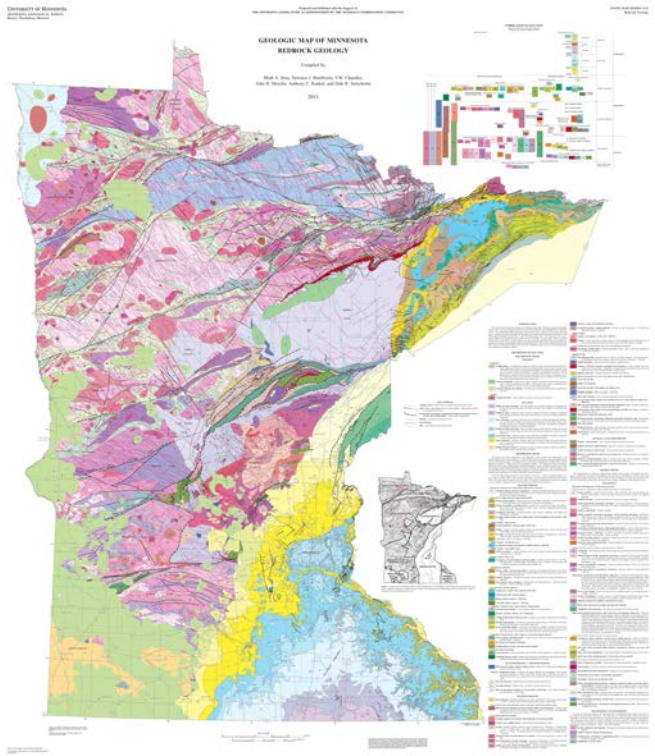
MGS Mission

Minnesota Geological Survey serves the people of Minnesota by providing systematic geoscience information needed to support stewardship of water, land, and mineral resources. MGS geological mapping and research evolve with the progress of science and technology, and the MGS works closely with university, government, industry, and community partners to ensure that we respond to the diverse needs of the people.

MGS History

In 1872, the Legislature established the Geological and Natural History Survey of Minnesota as part of the University of Minnesota, with Newton Horace Winchell as 1st Director. The Survey was discontinued upon Winchell's retirement in 1900 and publication of his Final Report on The Geology of Minnesota in 1901, although the natural history function later became the Bell Museum. In 1911, new Department Chair William H. Emmons of USGS specified reinstatement of a State Geological Survey as a condition of his acceptance, and he became 2nd Director of the Survey. Ensuing Directors, based in Pillsbury Hall, were Frank F. Grout in 1944, George M. Schwartz in 1948, and Paul K. Sims in 1961 – their era culminated with 'Geology of Minnesota: A Centennial Volume' in 1972, and a move off-campus, to Eustis Street in the 1970s, and to University Avenue in the 1980s. Matt S. Walton, appointed Director in 1973, oversaw expanded geophysical surveys to support mineral exploration, as well as initiation of drillhole databases and the County Geologic Atlas program. Priscilla C. Grew of California became Director in 1986, MGS geologist David L. Southwick succeeded her in 1993, and L. Harvey Thorleifson of the Geological Survey of Canada was appointed Director in 2003. The post-~2000 focus has been on optimizing statewide geoscience information needed for groundwater management.

Minnesota Geological Survey staff, June 2017



Current state bedrock map, published in 2011

MGS Publications, Mapping, and Databases

MGS is fulfilling its role primarily through 1:100,000 and 1:500,000 mapping of surficial geology, bedrock geology, subsurface geology, bedrock topography, and sediment thickness. The geological mapping is first published as authored and peer-reviewed geological maps, and is also being assembled as a 2-resolution, layered set of databases that includes the offshore, that underlies bathymetric and soil mapping, and that is as compatible as possible with neighbors. Efforts to refine stratigraphic nomenclature are ongoing. Progressively more seamless geological polygons, at 1:100,000 and 1:500,000, are tending to have thickness indicated, while properties, heterogeneity, and uncertainty will gradually be more specified. Parsing of legends, to facilitate queries, is using broadly accepted, well-defined terminology, to facilitate inference of properties. A layered 1:500,000 state bedrock geologic map is largely complete, although for Precambrian layers the thickness and underlying geology have not yet been specified, while a new state Quaternary geology map is in development. New 1:100,000 mapping is being completed as County Geologic Atlases, is meant to be complete statewide within a decade or so, and is focused on societal needs, with an emphasis on groundwater protection and management, while taking a broad approach. Where required to resolve issues, 1:24,000 mapping is conducted. The geological mapping is accompanied by associated spatial databases. The publication database, which is spatial through publication footprints, includes nearly 50,000 pages, and 700 scanned maps, both searchable and web accessible. Geological databases include field observations, drillhole data, karst features, as well as sediment texture and lithology. Geological collections include cuttings, geochemical samples, hand samples, sediment samples, and thin sections. Geophysical databases include borehole geophysics, gravity, magnetic, rock properties, and soundings; geochemical databases include groundwater, soil, and soil parent material; while geochronological databases are in development. MGS coordinates with the DNR drill core library and mineral exploration document archive, the Bell Museum fossil collection, and the DNR aquifer properties database.

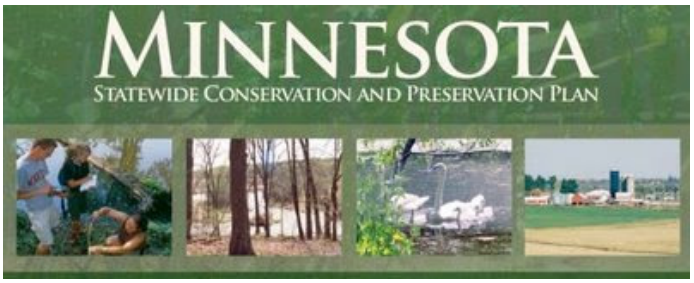
County Geologic Atlas Program

County Geologic Atlases provide information essential to sustainable management of groundwater resources, for applications such as aquifer management, ground water modeling, monitoring, permitting, remediation, water allocation, well construction, and wellhead protection. Atlases define aquifer properties and boundaries, as well as the connection of aquifers to the land surface and to surface water resources. They also provide a broad range of information on county geology, mineral resources such as construction materials, and natural history. The atlases thus are also useful to consultants, exploration efforts, educators, and citizens.

A complete atlas consists of a Part A prepared by MGS that includes the water well database and 1:100,000 scale geologic maps showing properties and distribution of sediments and rocks in the subsurface, and a Part B constructed by DNR that includes maps of water levels in aquifers, direction of groundwater flow, water chemistry, and sensitivity to pollution. Atlases in most cases are initiated by a request from a county and an offer to provide in-kind service. A User's Guide to Geologic Atlases helps non-geologists understand the information products and their uses. Atlases are available in print, or in digital formats, including pdfs and GIS files.

Planning and Progress

MGS priorities have been specified by a series of broadly consultative State resource planning exercises.

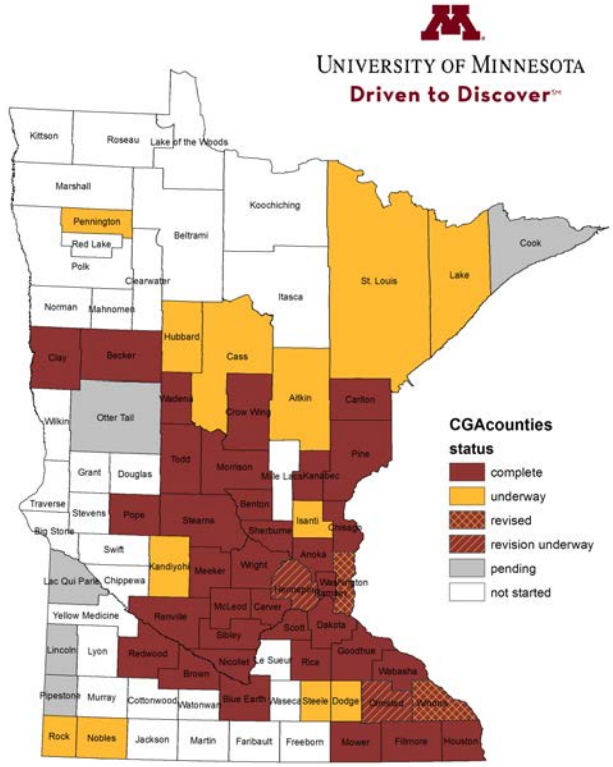


The Statewide Conservation and Preservation Plan was initiated by the Legislature in 2006. The intent was an integrated inventory and assessment of Minnesota's environment and natural resources that could guide decision-makers on future short and long term planning, policy, and funding. A recommendation to improve understanding of groundwater resources focused on development of a large-scale, hydrologic-system framework for understanding how today's decisions may affect tomorrow's needs. This recommendation specified statewide coverage of county geologic atlases or comparable information products as being needed.

In 2011, the Minnesota Water Sustainability Framework further advocated that a measure of our progress in obtaining a complete picture of groundwater resources in Minnesota should be the rate of completion of county geologic atlases by MGS and DNR. The report therefore advocated that the pace of completion of the county geological atlases by the MGS should, at a minimum, be doubled to allow completion within a decade,

followed by review and updating on a regular schedule. These recommendations then guided the Six-Year Strategic Plan for Minnesota's Environment and Natural Resources Trust Fund (ENRTF), which is administered by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). The Plan, completed in 2013, advocated statewide acquisition of County Geologic Atlases by the year 2020. MGS therefore is focused on completion and updating of County Geologic Atlases, while ensuring that we take a broad approach, and that we optimize the scientific quality of all related activities.

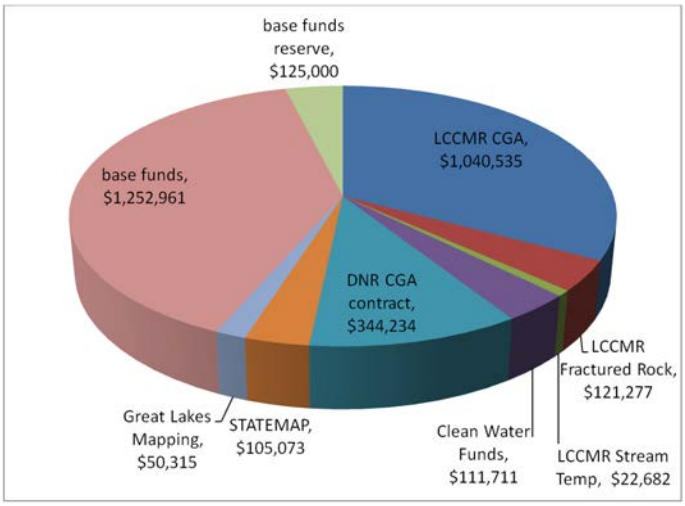
At this time, 33 counties are complete, 32 are not started, 5 are pending, 3 are revised, 2 revisions are underway, and 12 new Atlases are underway. Atlases are being completed at a rate of ~5 per year, so with nearly 50 completions remaining, statewide atlas coverage will be achieved in a decade, depending on the pace of revisions and accompanying research.



Status of County Geologic Atlas mapping

Resources

Funding: Whereas funding to the ~10,000 USGS employees is >$1B/year, total revenue to the ~1950 employees at State Geological Surveys in FY16 was $222M, down from the all-time-high of $237M in 2012 that related to the federal stimulus, although a current-year recovery to $230M is estimated. The average state geological survey thus consists of ~40 staff, who receive ~4.5M in funding. For MGS, funding this year is $2.9M, down from $3.4M last year, due to project cycles. While MGS funding averaged $2.3M from 2003 to 2008, the average since then has been $2.9M. MGS relies on about $1.2 million in base funding, and about $1.65 million in grants and contracts – primarily from the ENRTF through LCCMR – to meet our annual payroll of $2.85 million. Additional funding from both sources covers non-personnel costs such as travel, drilling, equipment, supplies, and services. This year, we underwent a financial and administrative audit that resulted in no concerns.



Sources of 2016-2017 expenditures

Staffing: MGS staffing was stable at 28 full-time-equivalents (FTE) from 2003 to 2012; since then, staffing has averaged 36 FTE. MGS is one of two state geological surveys in the USA whose staff, measured as FTE, is majority female – at 52%. This compares to 35% nationwide. We currently are 28 geologists, 4 information professionals, 2 administrative staff, and 6 students equivalent to ~3 FTE. The eight longest serving staff members have over 300 years' experience on the job. Transferring their knowledge to the next generation is an important priority.

Building: MGS was located in Pillsbury Hall from ~1890 until the 1970s. After a brief stay in Jones Hall, MGS moved in the 1970s to a building on Eustis Street in Saint Paul, followed by a

move to University Avenue in Saint Paul in the 1980s. In 2015, we moved to our current location on Territorial Road in St Paul. The new building has worked out well. Every work station is occupied, and the fit and function of the facility are very good.

Current Activities

Mapping: Mapping is focused on the 14 county geologic atlas projects that are underway.

Compilation: Barbara Lusardi is leading efforts on a new Surficial Geologic Map of Minnesota. This will be an update to the 1982 Geologic Map of Minnesota, Quaternary Geology by H.C. Hobbs and J.E. Goebel. The work is largely funded by a 1:1 cost-sharing agreement with the Great Lakes Geologic Mapping Coalition of the USGS. This multi-year project is stitching together many maps created by the County Geologic Atlas program and other mapping programs, and also filling in areas not yet mapped at the more detailed scale. The map follows construction of statewide cross-sections that depict the vertical and horizontal distribution of Quaternary sediment.

Databases: MGS manages several important geoscience databases that support our mapping, and activity by others across the state. The largest and most commonly used is County Well Index, which includes records for more than 500,000 wells, of which about 60% have accurate digital locations. We interpret the driller's description of the materials encountered in drilling and assign rock types and formation names. Our co-manager of this data, the Minnesota Department of Health, has contracted with MGS to add additional data from historical records. In addition, Julia Steenberg and Andrew Retzler are working on the 2nd of two projects that improve the usability of borehole geophysical and video data. In 2015, we inventoried and digitally converted analog natural gamma logs. The current project will inventory and update infrastructure for the multi-parameter, caliper, EM-flowmeter and borehole video logs.

Research: MGS undertakes research that is needed to optimize our mapping, such as enhanced hydrogeological characterization of sediment and rock strata. Tony Runkel, for example, is leading an effort to use new techniques of borehole testing and rock fracture mapping in the Twin Cities to improve understanding of groundwater flow through fractured rock, in order to better support groundwater management. The project is focusing on the Platteville Formation, a fractured limestone, which is one of the most heavily contaminated rock strata in the state. It also yields large springs that discharge to the Mississippi River, such as Camp Coldwater spring, and it is the foundation for much urban infrastructure. Pressure and temperature measurements collected from wells provide information on water flow through fractures, and when evaluated in the context of nearby fracture mapping at rock exposures, are allowing linkage of hydraulic properties to rock properties, thus providing a better understanding of fracture flow. Application of the results will improve the efficiency and effectiveness of remediation and monitoring at contaminated sites across the Twin Cities. The results will also be applicable to water management at construction sites, and to modeling groundwater-surface water interaction in areas such as the Minnehaha Creek Watershed.

Concurrently, as another example, Bob Tipping is leading a project to evaluate links between southeastern Minnesota stream temperatures, trout habitat, and bedrock hydrogeology to improve trout stream management. The goal of this project is develop and apply a temperature sensing method to candidate trout stream reaches to quantify the changes in temperature, flow, and trout distributions that occur along them. Advances in temperature measurements using fiber optic cables allow temperature to be recorded through time at regularly spaced intervals, over distances of 1 to 2 kilometers. Stream reaches to be measured are being chosen based on geologic mapping, focusing in areas where different geologic conditions exist and information on trout distribution and abundance are available. Both projects are funded by the ENRTF via LCCMR.

Plans for 2017-2018

Proposals:

- Submit proposal to LCCMR for $4M to support continued production of County Geologic Atlases; submit proposals to STATEMAP, Great Lakes Geologic Mapping Coalition, USGS Data Preservation programs

County Geologic Atlas Program:

- Complete and print county geologic atlases for Hubbard, Hennepin, Cass, and Isanti Counties; complete bedrock mapping for St. Louis and Lake Counties (compilation to follow); complete field work to support surficial geologic map of Aitkin County; conduct rotasonic drilling in St. Louis, Lake, Kandiyohi, Dodge, Olmsted, Rock, and Nobles; complete surficial geologic maps for Dodge, Olmsted, Rock, Nobles, and Kandiyohi Counties; complete bedrock geologic maps for Rock, Nobles, Dodge, and Olmsted Counties; initiate a new atlas project in Steele County; support partner efforts to establish well locations in Cook, Otter Tail, Lac qui Parle, Steele, Lincoln, and Pipestone Counties

STATEMAP Program:

- Complete bedrock geologic map for the Mark Lake 7.5′ quadrangle, Open File finished map

Great Lakes Geologic Mapping Coalition:

- Complete compilation of new statewide 1:500,000 scale Quaternary Geologic Map - editing and production to follow

Research:

- Continued work on two funded projects addressing fractured bedrock hydrogeology and groundwater-surface water interactions in cold water streams; publication of results from sponsored projects, and research with relevance beyond provincial interests

Outreach:

- Outreach ranging from public inquiries to academic collaboration – focus on ensuring that our information products are used efficiently by peer agencies such as the Pollution Control Agency, DNR, industry, and counties