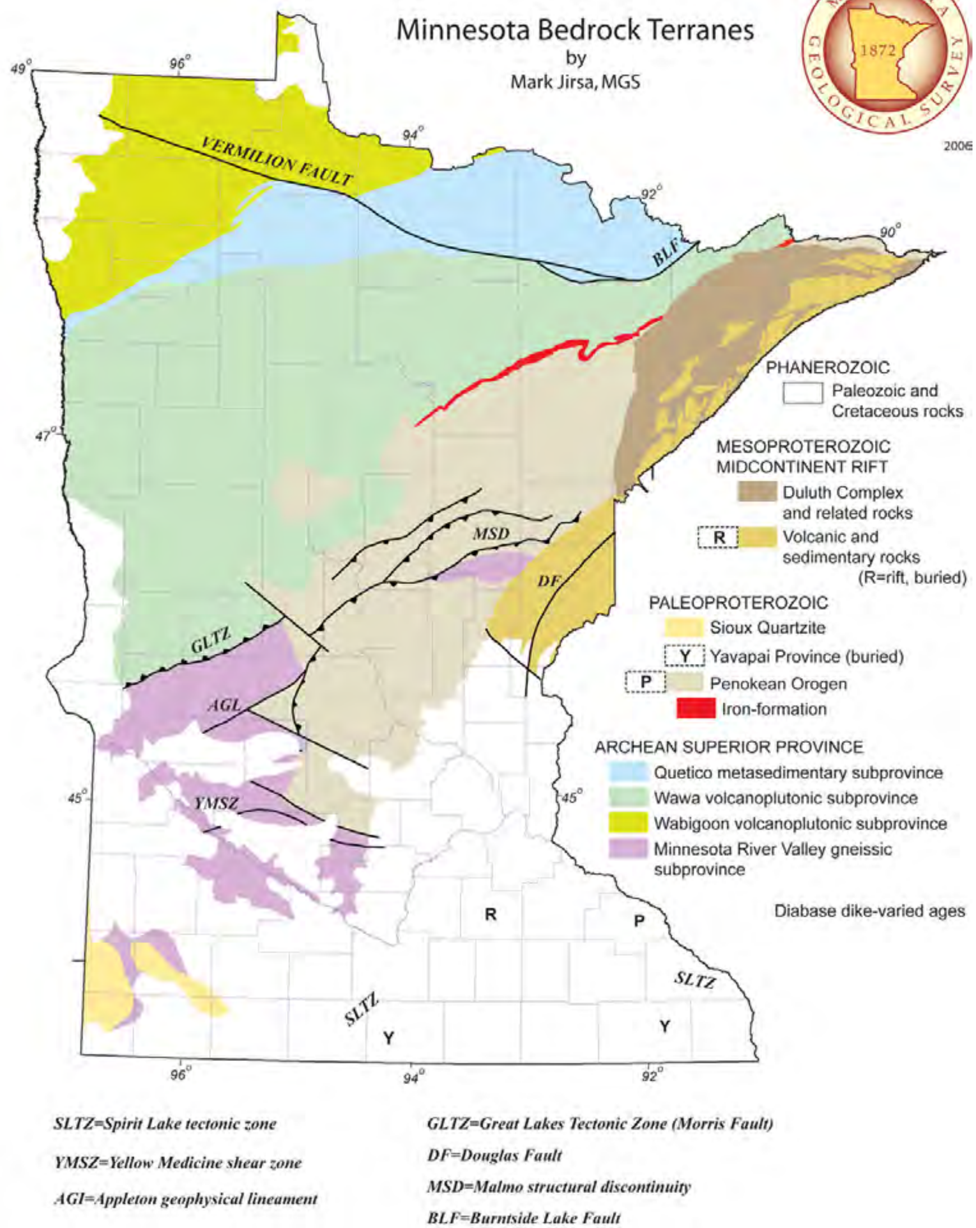
MINNESOTA GEOLOGICAL SURVEY
Harvey Thorleifson, Director



MINNESOTA DATA PRESERVATION REPORT FOR 2019/2020: UPDATED DATA INVENTORY, PRESERVATION OF PILLSBURY HALL ROCK COLLECTIONS AND DOCUMENTATION, ASSEMBLY OF MINERAL POTENTIAL RELATED INFORMATION

L. Harvey Thorleifson, Minnesota Geological Survey, Editor

A report prepared in fulfillment of National Geological and Geophysical Data Preservation Program Award Number G19AP00064; 1 July 2019 – 30 June 2020

Minnesota Geological Survey Open File Report OFR-20-1

University of Minnesota
Saint Paul – 2020

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MINNESOTA DATA PRESERVATION REPORT FOR 2019/2020: UPDATED DATA INVENTORY, PRESERVATION OF PILLSBURY HALL ROCK COLLECTIONS AND DOCUMENTATION, ASSEMBLY OF MINERAL POTENTIAL RELATED INFORMATION

This report is accessible from the web site of the Minnesota Geological Survey (https://cse.umn.edu/mgs) as a PDF file.

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PREFACE: *L. Harvey Thorleifson*

This report was prepared to fulfill National Geological and Geophysical Data Preservation Program (NGGDPP) FY19 Award G19AP00064, for which work was carried out from 1 July 2019 to 30 June 2020, in support of the Department of Interior Secretarial priority to sustainably develop our energy and natural resources.

Minnesota Geological Survey (MGS) activity is focused primarily on recommendations of Legislative panels that indicate that statewide coverage of layered County Geologic Atlases will be needed to support management of water resources, while concurrently being needed for applications such as mineral resources, engineering, hazards, and research. All MGS activity is reliant on geological specimens, as well as geological, geophysical, and geochemical data. MGS therefore has strived to contribute to the objectives of the NGGDPP.

The MGS long-term data preservation plan prepared in 2009 identified the highest priorities in relation to applications such as groundwater management and mineral resource assessment. Included were: 1) reprocessing of the aeromagnetic database; 2) enhancement of location precision for gravity stations; 3) vertical georeferencing of the rock property database; 4) cataloging and georeferencing of rocks and thin sections stored at the building MGS occupied from 1983 to 2015; 5) standardized formats for existing databases; and 6) scan and web enable all publications. More recently, a need was recognized for: 7) scanning, digitizing, and enhanced cataloging of borehole geophysical records, 8) comprehensive regional geophysical survey rescue, 9) enhancements to the cuttings collection and database.

Objectives 1, 2, and 3 were completed with State of Minnesota support. Objective 4 was completed with multiple years of NGGDPP support. Objective 5 is ongoing. Objective 6 was completed with University of Minnesota Library support. Objective 7 was completed for gamma logs with our 2015 NGGDPP grant, and was completed for all borehole geophysical logs due to 2017 NGGDPP support. Geophysical survey rescue will remain unfulfilled due to staff availability constraints. Work on cuttings will be carried out due to NGGDPP support during 2020/2021.

The FY19 NGGDPP Program Announcement indicated three priorities: Priority 1 – Inventory geoscience materials and update National Digital Catalog (NDC) records; Priority 2 – Preserve geoscience data and materials; and Priority 3 – Identify Critical Mineral Resources. MGS responded by proposing: 1) an updated collection inventory and metadata record revision for the NDC; 2) unforeseen preservation of historic survey, more recent survey, and thesis rock specimens that had been stored in the building MGS occupied from 1889 until 1970; and 3) assembly of requested mineral-potential-related information for the State of Minnesota.

The Priority 1 work focused on update of NDC records. This largely was an update of metadata derived from the Assessment of Preservation Needs and Long-Range Plan for Geologic Collections and Data in Minnesota that was prepared in 2009. In relation to this work, one member of MGS staff, J. Hamilton, attended the NGGDPP Data Preservation workshop held in Denver in September 2019, at project expense.

Work under Priority 2 focused on preservation of rock collections that had been stored in Pillsbury Hall, where MGS was located from 1889 until 1970, with associated and additional documentation. These collections largely consisted of several thousand rocks collected by the surveys led by the first MGS Director, Professor Newton Horace Winchell between 1878 and 1898. In addition, many crates of rocks related to later survey projects and thesis collections, mostly from the Duluth Complex of northeastern Minnesota. In addition, field notebooks and maps associated with the Pillsbury Hall rocks were scanned, and information that can be associated with each sampling site was entered into the appropriate database. To the extent possible, thin sections associated with the rocks that are in MGS collections were linked to the rocks and associated metadata in the database. Additional MGS field notebooks and field maps that relate to projects near those from which the Pillsbury Hall rocks were derived, in similar geology, in most cases Duluth Complex, also were scanned. This will support further documentation of the collection, which now totals about 60,000 specimens after addition of the Pillsbury Hall rocks.

Work carried out under Priority 3 assembled requested information that supports identification of critical mineral resources in Minnesota. Public-domain mineral-potential-related information in Minnesota is primarily maintained by University of Minnesota's Minnesota Geological Survey (MGS) located in the Twin Cities, the State Department of Natural Resources (DNR), and by the University of Minnesota Natural Resources Research Institute (NRRI) in Duluth. The work therefore was carried out as a coordinated effort of these agencies.

MGS coordinated work by the three agencies to assemble or construct information, compile explanatory documents, and provide resulting databases. In support of these activities, one member of DNR staff, D. Dahl, and one member of NRRI staff, G. Hudak, attended a USGS-hosted workshop in autumn 2019, the latter at project expense.

As requested, the provided information includes information assembled by Dave Dahl of DNR: mineral deposits and occurrences, a database for publicly available drill core, and an indication of areas of ongoing mineral exploration.

Requested geospatial representations of areas that delineate prospective areas or geologic belts with the potential for hosting critical mineral resources were assembled in two components. First, Mineral Deposits Geologist George Hudak of NRRI prepared a document briefly describing published research specific to Minnesota that supports inference of mineral potential on the basis of geological mapping, and a bibliography listing references for published literature on this topic.

Second, MGS staff enhanced digital bedrock geological mapping databases to better provide information needed to identity focus areas with the potential to host critical mineral resources

In addition, Appendix A summarizes Minnesota Earth MRI Confluence documents and data uploaded to the USGS Confluence web site on 12-14-2019. Appreciation is expressed to Dave Dahl of DNR for coordinating this submission.

The compiled mineral-potential-related information therefore includes:
1. readily available DNR digital information for mineral deposits and occurrences, using nonproprietary data and assembled digitally in the template provided by USGS
2. an explanatory document and digital database for publicly available drill core at DNR
3. an explanatory document and digital GIS database to indicate ongoing mineral exploration activities, based on the extent of active mineral leases on file at DNR
4. an NRRI document describing published research specific to Minnesota that supports inference of mineral potential from geological mapping, and a bibliography listing references for relevant published literature
5. explanatory documentation and digital MGS GIS databases for:
    a) modelled grids depicting current knowledge for: 1) depth to bedrock, 2) depth to pre-Mesozoic, 3) depth to Precambrian, and 4) depth to basement
    b) layered 1:500,000 statewide bedrock geological mapping, from which Mesozoic, Paleozoic, and Precambrian cover rocks can be removed to reveal a basement map
    c) 1:100k detailed bedrock geology maps covering half the state, assembled as a GIS resource without harmonization, with legends coded in a manner consistent with the 1:500,000 mapping
    d) a pilot statewide structure database derived from MGS maps
    e) a pilot statewide outcrop database based on MGS mapping
    f) statewide Precambrian geochronological database.

CHAPTER ONE: National Digital Catalog collection inventory and metadata record update for Minnesota, *Minnesota Geological Survey Staff*

In FY19, National Geological and Geophysical Data Preservation (NGGDPP) Priority 1 focused on inventory of geoscience materials and update of National Digital Catalog (NDC) records.

NDC updates were to include complete metadata records for all existing entries in the NDC, which could require over-writing of previous entries. It was indicated by the program that new metadata records describing physical geoscience collections could be added to the NDC.

Minnesota Priority 1 work in FY19 focused on update of NDC records.

The original collection metadata had been based on the Assessment of Preservation Needs and Long-Range Plan for Geologic Collections and Data in Minnesota that had been prepared in 2009. This inventory included collections and databases that MGS maintains, and to which MGS contributes.

In relation to this work, one member of MGS staff, J. Hamilton, attended the NGGDPP Data Preservation workshop in September 2019, at project expense.

At present, in August 2020, the NGGDPP NDC records for Minnesota include nineteen collections:

1. Aeromagnetic database
2. Borehole geophysical logs
3. Cuttings
4. Drill cores
5. Field notebooks
6. Geochemical Data
7. Geochemical samples
8. Geological mapping data
9. Geotechnical drilling
10. Gravity database
11. Hand samples
12. Karst database
13. Mineral exploration files
14. Paleontological samples
15. Rock properties database
16. Sediment samples
17. Sediment textural and lithological data
18. Thin sections
19. Well logs

Metadata at a level more specific than collection has been added since 2009 in relation to NGGDPP-funded work, related to borehole geophysical logs, field notebooks, hand samples, and thin sections.

Under the FY19 work, metadata records were updated as needed, such as replacement of obsolete web addresses.

CHAPTER TWO: Preservation of Pillsbury Hall rock collections with associated and additional documentation, *L. H. Thorleifson, A. R. Block, Minnesota Geological Survey (MGS)*

Work under Priority 2 focused on preservation of Pillsbury Hall rock collections with associated and additional documentation. Over the winter of 2018/2019, it became apparent that a significant data preservation project involving about 11,000 rocks would be needed in relation to Survey materials that to some extent can be regarded as historic and that were located in Pillsbury Hall on the University of Minnesota campus, the building MGS occupied from 1889 until 1970 (Figure 2.1). For all of these collections, there is a significant possibility that these materials will be needed in the future to support research on mineral resources and regional geology. The work thus addresses the Department of Interior Secretarial priority to sustainably develop our energy and natural resources. All are research and survey collections with specimen IDs, locations, and significance of the specimen indicated in associated documentation. Effort was needed to repackage and relocate the specimens at UMN expense, prior to the contract period, and to assemble digital information required to facilitate the potential future use of the materials, with NGGDPP support, under the contract.

In 1872, the Minnesota Legislature directed the University of Minnesota to initiate the Minnesota Geological and Natural History Survey. As a result, the University employed Professor Newton Horace Winchell, who became one of the founders of the Geological Society of America, and the geologist who accompanied General Custer into the Black Hills of South Dakota in 1874 during his time as 1st Minnesota State Geologist. After having made seventeen years of progress, the resulting Survey, Department, and Museum moved into the newly constructed Pillsbury Hall on the University of Minnesota campus in 1889. Winchell completed the survey that he had been commissioned to carry out in 1901, at which time the Survey was disbanded, although the natural history function became the Bell Museum. Following a 10-year hiatus, the Survey function was restored as Minnesota Geological Survey in 1911. Eventually, the Survey moved off-campus in 1970.

Rock specimens curated by Professor Winchell and his co-workers remained, however, in Pillsbury Hall. Perhaps due to the accelerating pace of Survey work that necessitated the move off-campus, the Winchell rocks were repackaged in cardboard boxes and moved to the Pillsbury Hall subbasement in about 1969 – these are referred to here as *the Winchell rocks*. Several thesis and survey rock collections in crates were already being stored in this area, along with multiple non-Minnesota research collections, and more were added in later years – these will be referred to here as *the crates*. Among the MN rocks in crates, many are from the Duluth Complex of northeastern Minnesota – an area at present of very active exploration and development for copper-nickel-PGE. Also present in the basement was a large collection of Precambrian cores collected in MN, WI, and MI by the Air Force. The subbasement was sealed off in the 1990s due to concerns about asbestos. Awareness of the materials began to fade, and confidence that the materials could ever be recovered began to diminish. Water leaks, it seems, took their toll, based on photographs taken in 2014 by a crew in protective gear (Figure 2.2).

In 2017, however, after 128 years in Pillsbury Hall, the Department moved to newly renovated space. Resolution of the subbasement was finally addressed in late 2018, at which time about half of the subbasement materials, including obsolete equipment, all paper, and specimens that had been exposed, were discarded by an abatement crew. Remaining materials were washed, and then moved up to a working area on the basement level by the crew (Figure 2.3). In early 2019, it was recognized that the recovered materials included about 6000 rocks from the Winchell survey, and ninety-six 50-kg crates containing an additional ~5000 specimens. Fifty-five of the crates related to Minnesota-based thesis and survey projects from the 1950s to the 1990s – a total of about 2000 rocks. Department and Survey personnel worked in coordination to reconcile the materials. It was decided to add all MN-derived specimens to the MGS database. An additional 41 crates that contained non-MN research specimens, a total of about 3000, were deemed the responsibility of the Department. Nearly all of the ~6000 Winchell rocks, having been removed from their cardboard boxes and placed in a pile, could be seen to have varying formats for unique ID, such as ink color, or letter suffixes. The rocks therefore were placed into groups according to labelling style (Figure 2.4). About a thousand of the Winchell rocks that had lost their label were discarded. The remaining Winchell rocks were packed in twenty new crates (Figure 2.5) numbered Winchell1 to Winchell20 (Figure 2.6). Air Force cores from WI and MI were shipped to those states. MN-derived specimens from Voyageurs National Park were placed in the custody of the Park, and samples from Mystery Cave were delivered to the Cave. The Precambrian stromatolites from the Biwabik and Gunflint Formations were retained at UMN Tate to support current research (Figure 2.7). The Winchell rocks in new crates, the old crates, and the MN Air Force cores (Figure 2.8) were then shipped to DNR in Hibbing on April 1, 2019 (Figure 2.8). Appreciation is expressed to DNR for their willingness to store the materials in their staffed, very-well-maintained storage facility, as has already been done with NGGDPP support for over 49,000 rocks in MGS collections. All of these materials are now available to the public for potential utilization according to repository policies.

In early 2019, it therefore was proposed to NGGDPP that all of the MN rocks, or at least those with surviving labels and associated locations and other data, be cataloged by technicians and/or students under the supervision of MGS geologists, and documented at least with estimated digital locations. In addition, field notebooks and maps that are associated with the Pillsbury Hall crates were scanned by University of Minnesota Libraries. Additional information that can be associated with each sampling site was entered into the appropriate database. To the extent possible in the circumstances, thin sections associated with the rocks that are in MGS collections were linked to the rocks and associated metadata in the database.

Additional MGS field notebooks and field maps that relate to projects near those from which the Pillsbury Hall rocks were derived, in similar geology, in most cases Duluth Complex, also were scanned. This documentation had recently been assembled, and can now support further documentation of the collection as a whole, which now totals 54,833 specimens after addition of the Pillsbury Hall rocks. The field notebooks and field maps directly associated with the non-Winchell Pillsbury Hall rocks, plus the associated notebooks and maps, include the work of geologists Beltrame, Cooper, Davidson, Day, Green, Jahn, Miller, Perry, Phinney, Severson, and Weiblen.

Winchell rocks: The Winchell rocks are listed in Minnesota Geological and National History Survey Annual Reports 9, 10, 13, 15, 16, 17, 18, 20, 21, 22, 23, and 24, which are available on the MGS web site. Information entered in the database for each rock, as reported in these Annual Reports, included ID, date, label format, lithology, geologist, locality, reference, as well as quarter, section, township, and range if reported.

Each specimen was given an estimated location, based on a nearby geographic location mentioned in the report. More accurate locations could partially be achieved by utilizing the section, township, and range location, with quarter sections and quarter-quarters often indicated. Locations in this format were indicated for half of the specimens, and these were entered in most cases, with NH Winchell rocks in AR15 being one exception.

A total of 6296 specimen ID numbers are listed in the reports (Table 2.1), and the total number of specimens is larger than this number, due to inclusion of rocks with ID numbers repeated, followed by suffixes such as A, B, and C. By accounting for specimen ID numbers with suffixes, a total of 6851 specimen records resulted. The specimens were collected by eight geologists as follows, with the number of rocks collected by each indicated: A. Winchell (1391), A.D. Meeds (61), A.H. Elftman (783), H.V. Winchell (726), J.E. Spurr (215), M.E. Wadsworth (31), N.H. Winchell (2409), and U.S. Grant (1235). The specimens were collected from 1878 to 1898. The number of specimens collected each year (Figure 2.1) was: 1878 (520), 1879 (420), 1880 (0), 1881 (0), 1882 (0), 1883 (0), 1884 (27), 1885 (0), 1886 (785), 1887 (1718), 1888 (578), 1889 (107), 1890 (19), 1891 (444), 1892 (380), 1893 (933), 1894 (86), 1895 (479), 1896 (116), 1897 (207), and 1898 (32). There is no indication that rocks from the 1874 Custer expedition are present. Most of the rocks are from northeastern MN (Figure 2.11); additional rocks are from elsewhere in Minnesota, as well as specimens from South Dakota, Wisconsin, Michigan, Ontario, and New York State.

The specimens were placed in crates, grouped according to labelling style, in 20 crates numbered Winchell1 to Winchell20 (Table 2.2). There was no effort to confirm which rocks are present, and which are not, as this task was deemed to be beyond the scope of the current activity. These are now in storage at the DNR facility in Hibbing MN. Each geologist used a designated specimen ID ink color, and/or a suffix specific to that geologist. There is uncertainty, however, in some of the colors, such as ink reported at the time to be white, and perhaps now looks pink, and in another case, what originally was green might now look black. Nevertheless, the rocks were placed in like groups, and further study of numbers and lithology (Table 2.3) in relation to the Annual Reports would clarify the linkage between the listing of rocks and the crates, should there be a desire to use the rocks. Assignment of each specimen to a crate in the database is uncertain, however. If a rock is indicated to be in a crate that contains rocks of a certain label format, it is equally likely it is in another crate of this format.

Crates: The Department had compiled a listing of specimens in most of the crates. The quality of data preserved in the inventory was variable among different geologists and projects, but the best-attributed collections included crate number, author, project year, project title, sample numbers, sample descriptions, and other notes. Many projects spanned multiple crate numbers. All data available in the hand-written inventory, which had been scanned and which can be made available if needed, was entered into a database by MGS staff. The database was then divided into MN-derived specimens that were added to the MGS hand sample database, and the remaining records, for non-MN materials, which were turned over to the Department. Several crates that had been moved from Pillsbury Hall to MGS by Professor Paul Weiblen in the early-2010s were not included in the new database, as these specimens had been added to the MGS database, and repackaged in white bankers' boxes, with NGGDPP support, at the time (Table 2.4).

The count of the crate specimens was as follows: Bor-ming Jahn (194), Eugene Perry (one collection), Jodi Milske (41), John Tabor (280), Long Island Lake (one collection), Paul Weiblen Moose Lake (one collection), Phinney Duluth Complex (394), Phinney Gabbro Lake (167), Phinney Little Gabbro, Gabbro, Bald Eagle (436), Roland Mohr (196), Sandy Beitsch (one collection), Warren Day (72).

Each specimen was given an estimated location, based on a nearby geographic location mentioned in the report, or the specimens were placed at the centroid of the study area. Actual locations could be obtained from the theses or publications, although digitally capturing these was deemed to be beyond the scope of the current activity. When individual sample numbers were listed for a crate, and when a list of sample locations could be found in literature for each project, a centroid was assigned to the particular samples in that crate rather than the entire project which often spanned multiple crates.

Scanning: MGS contracted with the Elmer L. Andersen library on the UMN campus to complete scanning objectives as part of this data preservation project. We obtained high-resolution scans and/or photographs of three types of historic field data: (1) field notebooks from historic bedrock mapping projects (2) field bedrock outcrop maps with mylar overlays, and (3) large-format geologic maps, traverse maps, and topographic quadrangle field maps containing geologic field data.

Details and quantities of each category are as follows:

- Field Notebooks:
    - John Green - former University of Minnesota Duluth (UMD) geology professor
        - 49 notebooks
        - Approximately 4,345 pages
    - Jim Miller - former MGS geologist and geology professor at UMD
        - 17 notebooks
        - Approximately 7,540 pages
    - W.C. Phinney - former MGS geologist
        - 6 notebooks

        - Approximately 300 pages
    - Mark Severson - retired Natural Resources Research Institute (NRRI) and private sector geologist
        - 5 notebooks/note packets
        - Approximately 406 pages
- Field maps with overlays:
    - Jim Miller
        - Photocopied topographic maps with mylar overlays displaying outcrop, structural measurements, and geologic units
        - 149 total maps
    - Mark Severson
        - Map sheets with transparencies of outcrop
        - 59 total maps
    - W.C. Phinney
        - Aerial photos with mylar overlays of outcrops
        - 19 total maps
- Large-format geologic maps, traverse maps, and topographic quadrangle field maps
    - John Green
        - 49 topographic maps (7.5 minute) with outcrop and field data
        - 1 oversized traverse map of field investigations of NE MN
    - Mike Mudrey
        - 1 field map with overlay
    - Mark Severson
        - 10 topographic maps (7.5 minute) with field notes
        - 4 geologic maps of Archean MN geology
    - Jim Miller
        - 1 topographic map containing field data
    - John Green
        - 2-sided field map accompanying field notebook
    - W.C. Phinney
        - 4 topographic maps (7.5 minute) containing field data

In total, 12,591 pages of field notes, 227 field maps with mylars, and 62 large-format maps were scanned or photographed as part of this project. MGS staff have archived these scans and made them available internally. The scans for now will be available to the public on request. When possible, the scans will be added to the existing web-accessible collection. Current MGS bedrock geologists have already begun to orthorectify the scanned field maps, and are using them to modify and attribute historic outcrops in northeast MN.

Linkages to thin sections: To the extent possible, thin sections associated with the rocks that are in MGS collections were linked to the rocks and associated metadata in the database. This was done with the assistance of T. Boerboom and R. Lively of MGS.

The catalogs of MGS hand samples and thin sections were brought into an ESRI geodatabase and made available internally to MGS staff. Due to sporadic work on this project in the past, the data sets were scattered over several locations with numerous copies and partially completed data tables.

Work over the past year resulted in archiving of the early versions and compiling the most current components into a master database, and making that database into one of several new MGS database series. The database series (D-series) is comprised of several types of Minnesota data that are statewide in nature and can be updated as needed without creating new publications for each update. Hand samples have locations and an attribute table of data. The hand sample/thin section database has the designation of d-10_rocksamples_thin_sections. Samples collected since release of the previous version were incorporated into this most recent compilation to bring it up to date as of early 2020. The hand sample database now contains over 46,196 entries, prior to addition of Pillsbury Hall rocks.

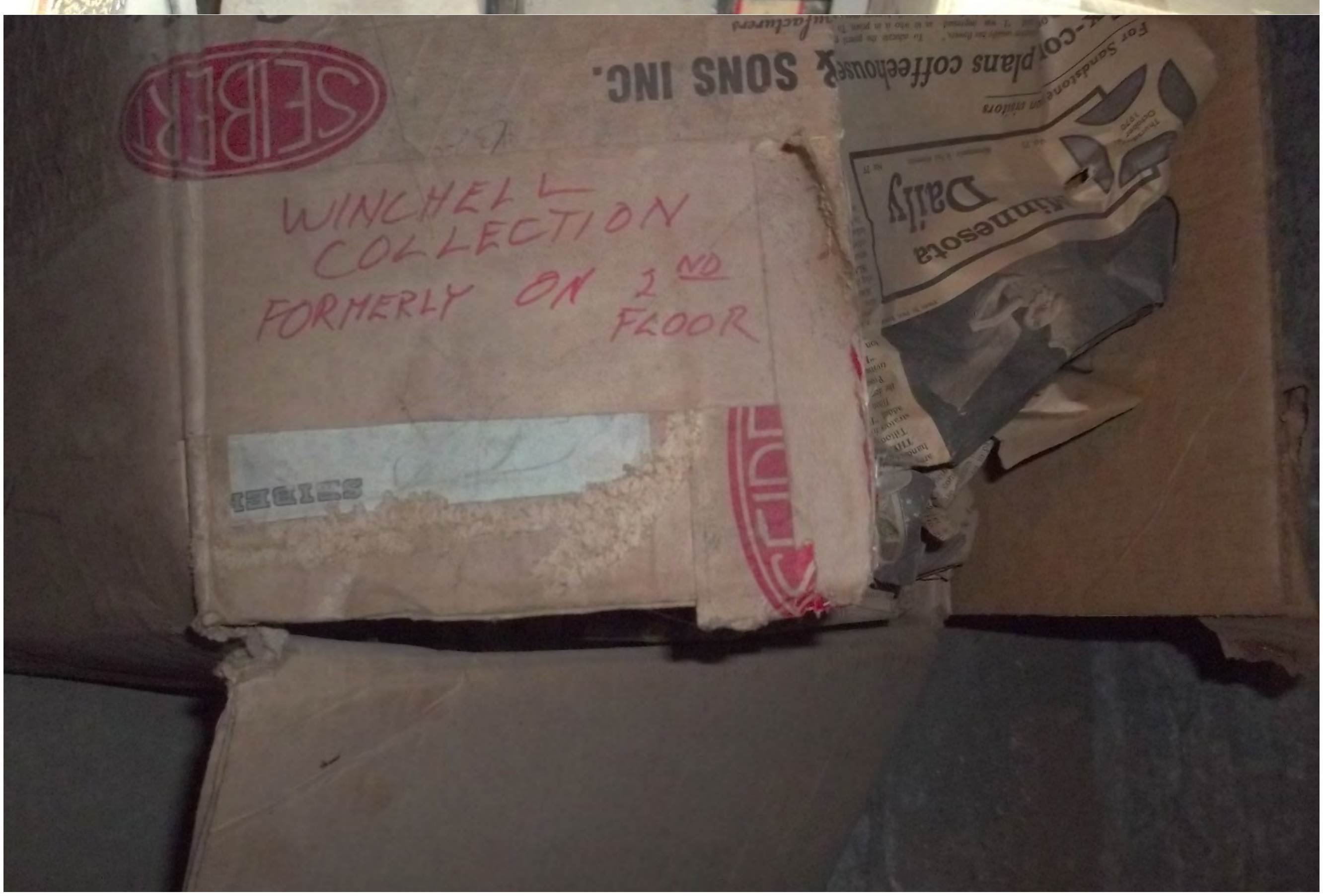
Many thin sections in the database are imperfectly located, as they temporally span the entire history of the MGS. The thin section database does have an attribute table of data that was filled out as the data were entered. Many of the thin sections made since the 1970s can be fairly easily located via old field maps and notebooks on file at MGS. Due to the large volume, thin section have been located on an as-needed basis, meaning that as we progress through different mapping project areas, every attempt is made to properly locate where the sample for the thin section was taken. As a result of ongoing mapping, several hundred thin sections have been better located, mainly in northeastern Minnesota in Cook and Lake Counties, in central St. Louis County, and Itasca County. All thin sections that were made since the advent of GIS and GPS are well located, having been stored with the data for individual mapping projects. In 2019, numerous samples were added to the thin section database using estimated locations so that the attribute table could be filled in with the proper data. As noted above, if a new area is being mapped, thin sections will be relocated as needed. The resulting thin section database now contains over 18,300 entries.

Dataset name:

Minnesota Winchell rock catalog
Minnesota Pillsbury Hall rock catalog

Figure 2.1 Pillsbury Hall

Figure 2.2 State of the Pillsbury Hall subbasement prior to abatement


WINCHELL
COLLECTION
FORMERLY ON 2ND
FLOOR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BOX 12 OF 14
HOLE NO. PB-CR-27
HOLE NO. PB-CR-27
BOX 6 OF 14
HOLE NO. PB-CR-27
BOX 8 OF 14
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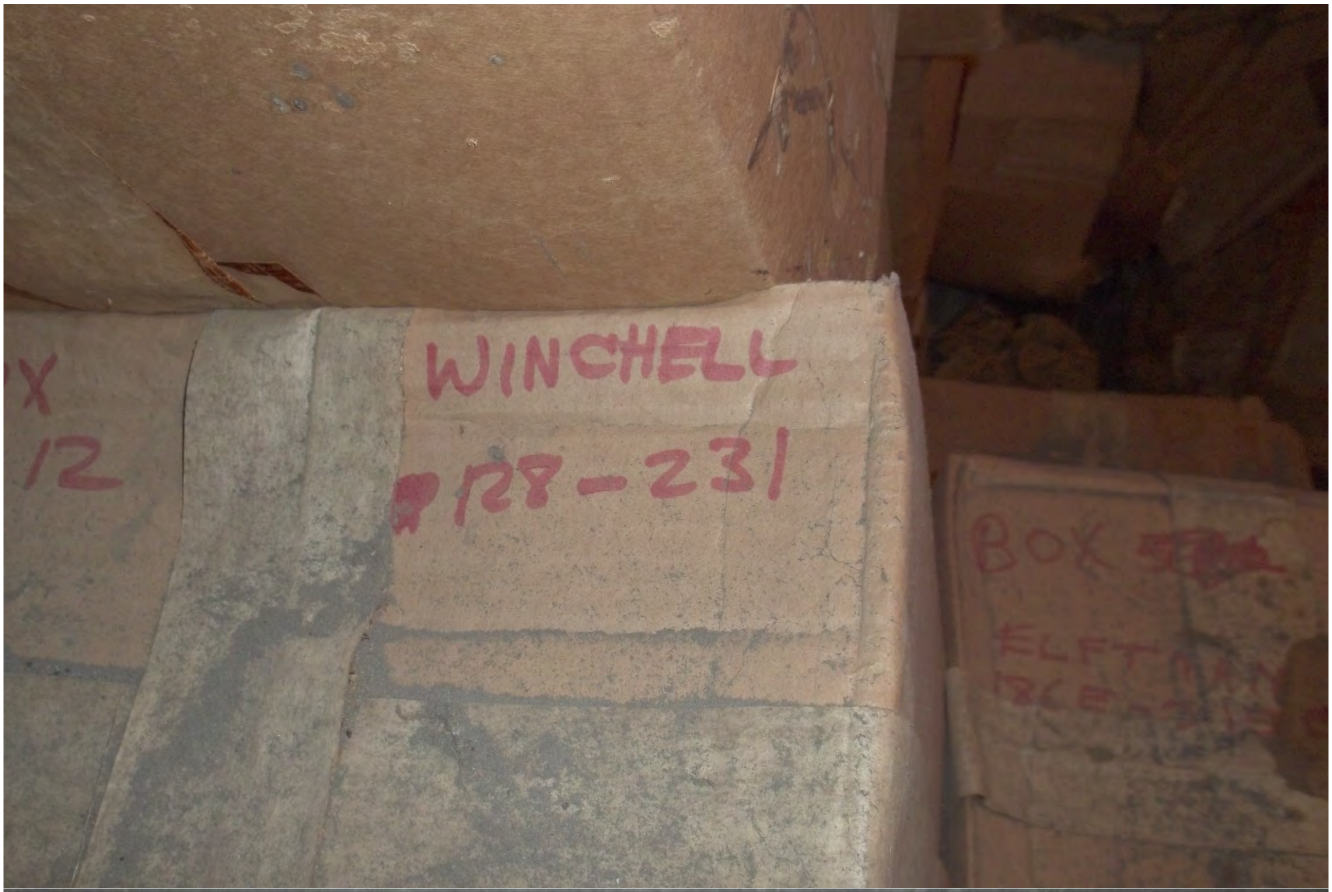
BOX 3 OF 15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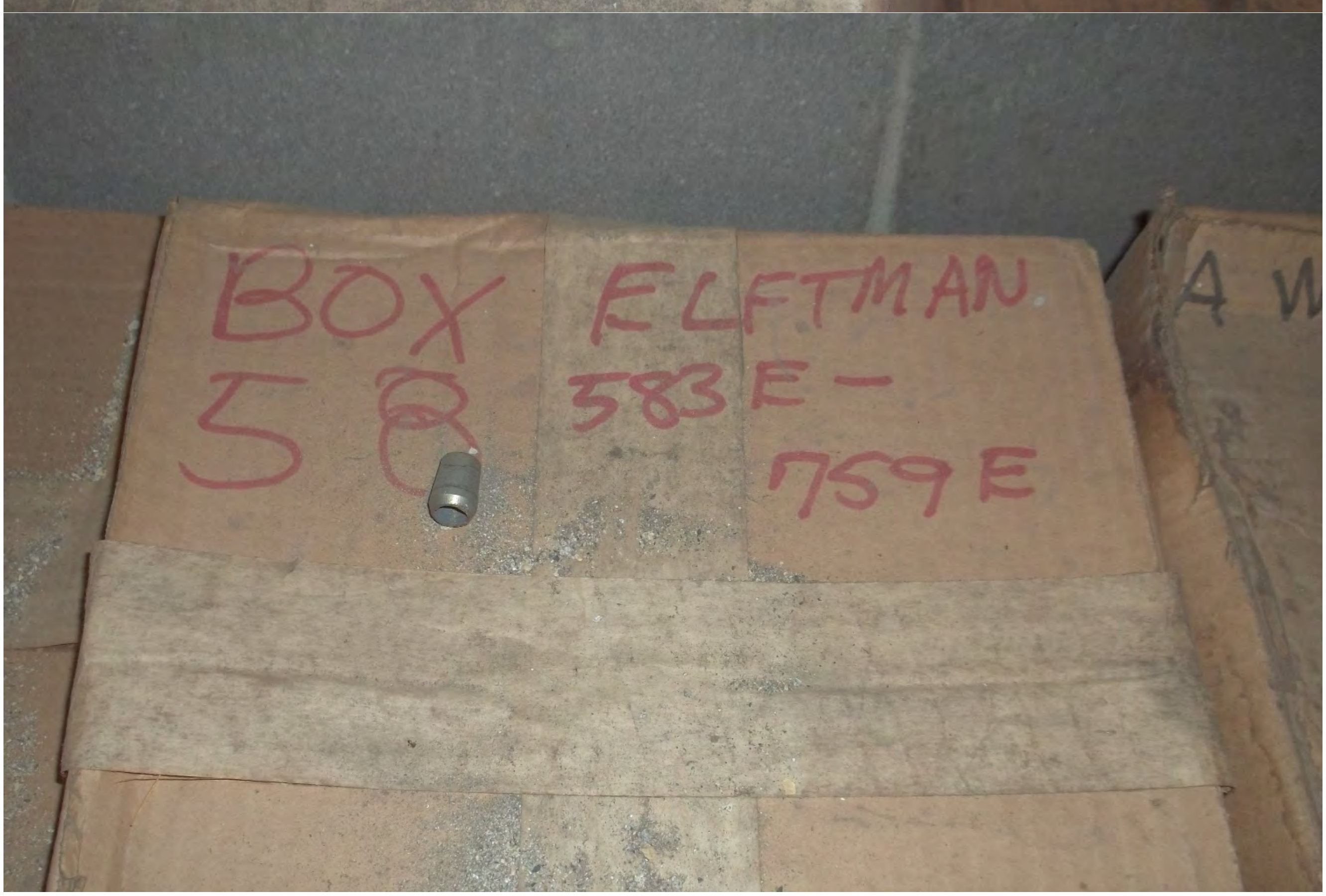
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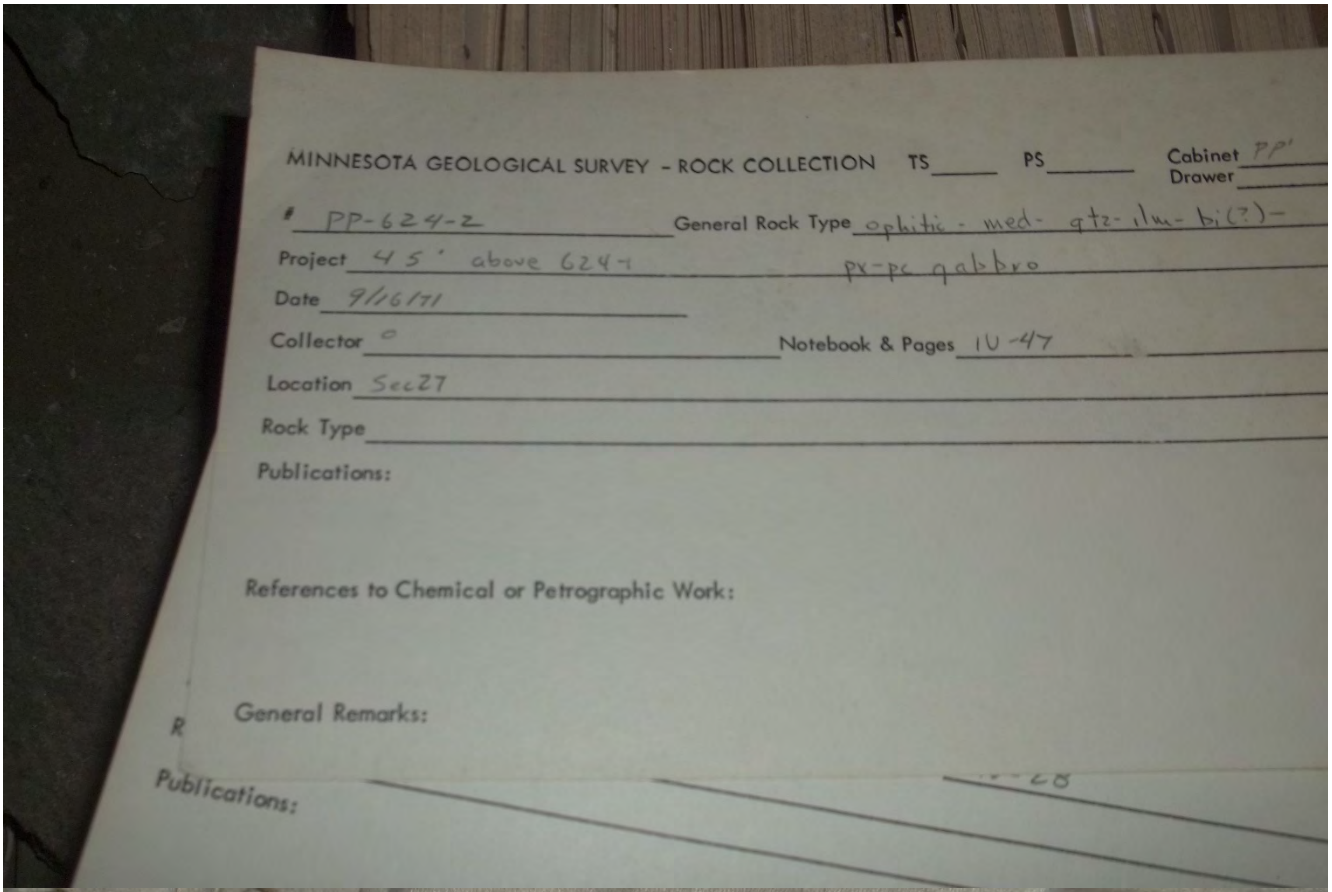
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Project 45' above 6244 px-pc gabbro
Date 9/16/71
Collector
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Location Sec27
Rock Type
Publications:
References to Chemical or Petrographic Work:
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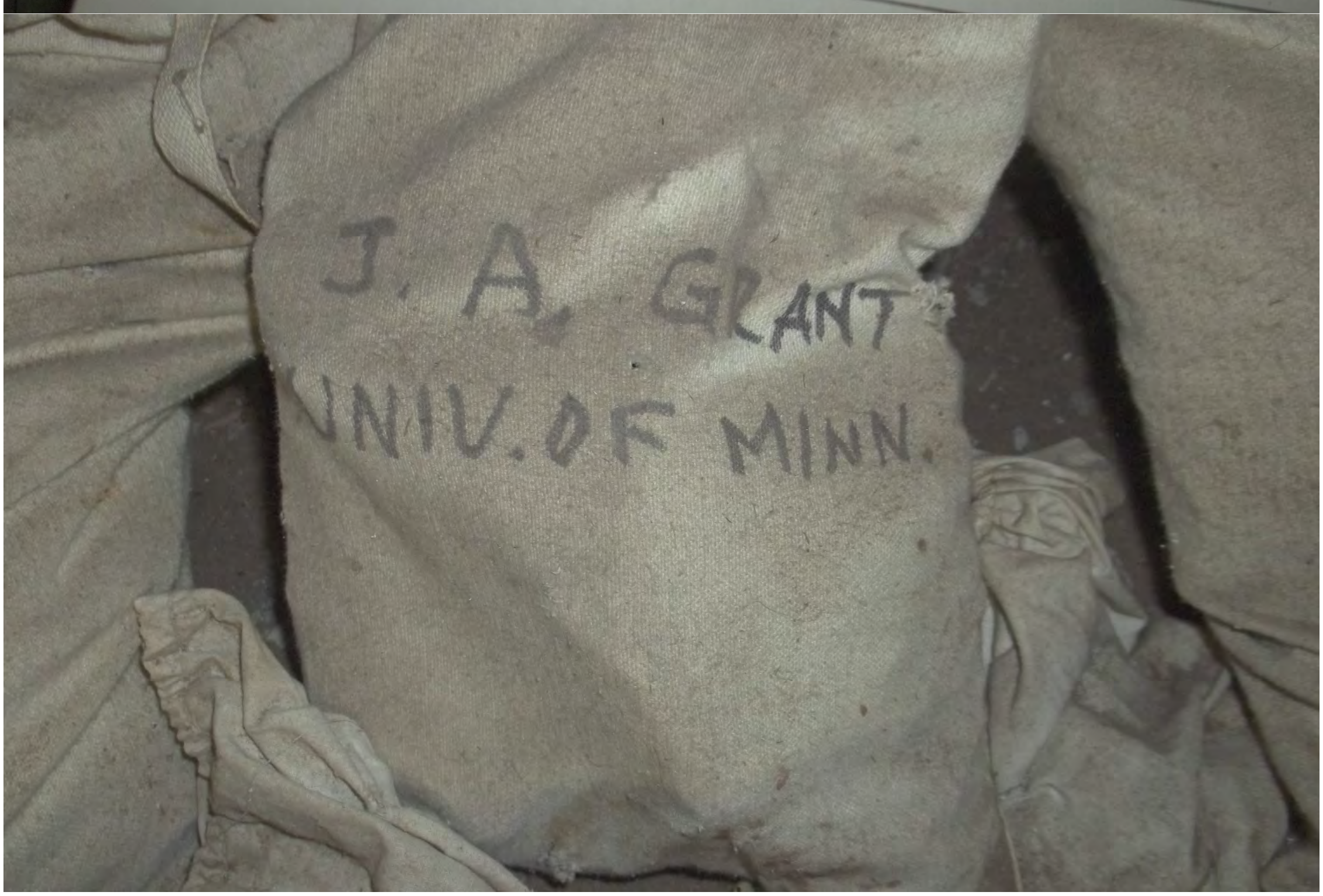
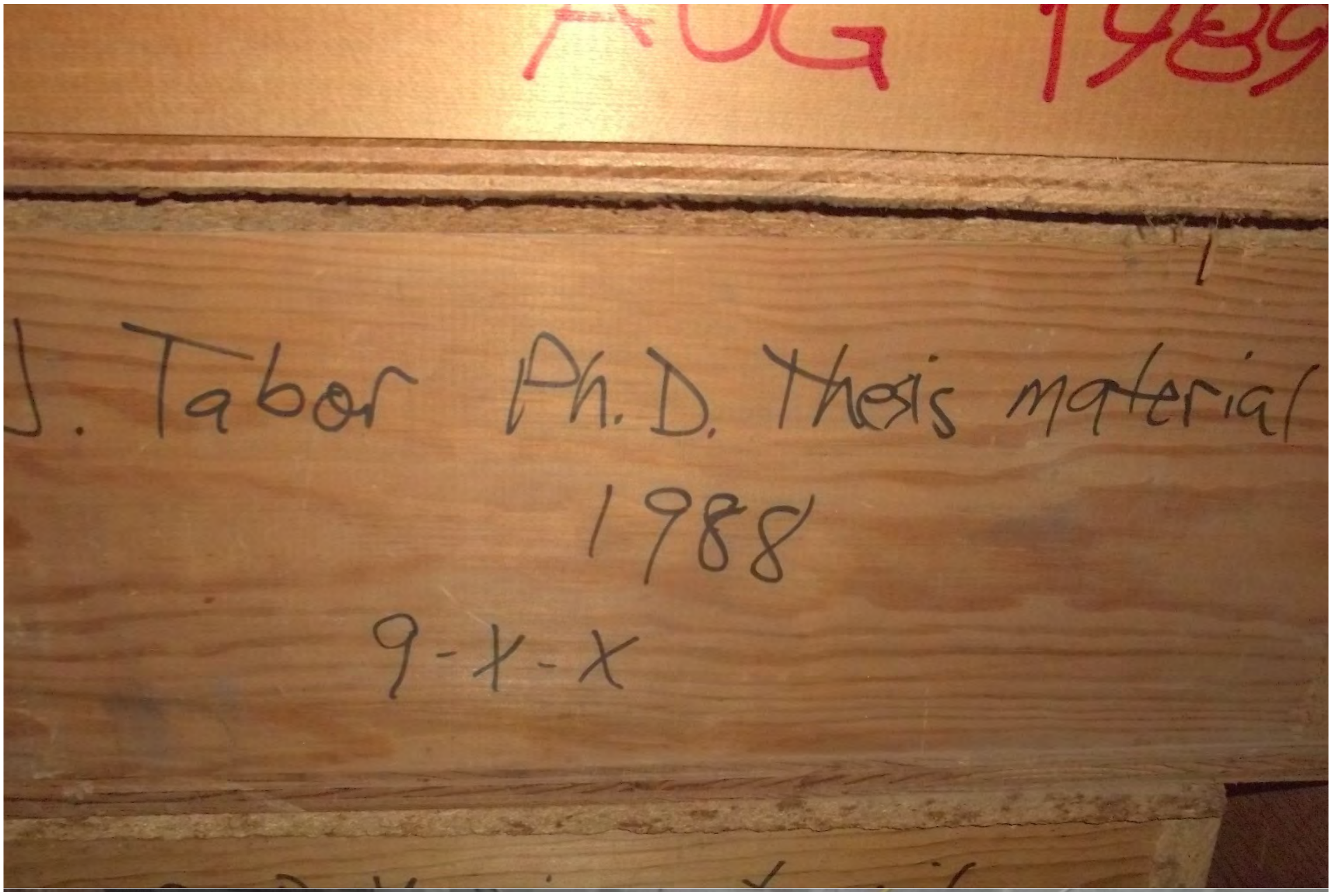

J. A. GRANT
UNIV. OF MINN.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Electronic
tubes


DANGER
ASBESTOS
CANCER AND LUNG DISEASE HAZARD
AUTHORIZED PERSONNEL ONLY
RESPIRATORS AND PROTECTIVE CLOTHING ARE REQUIRED IN THIS AREA

Figure 2.3 State of the Pillsbury Hall subbasement after abatement

Figure 2.4 Examples of Winchell rock-labelling types

Red paint with dark numbers

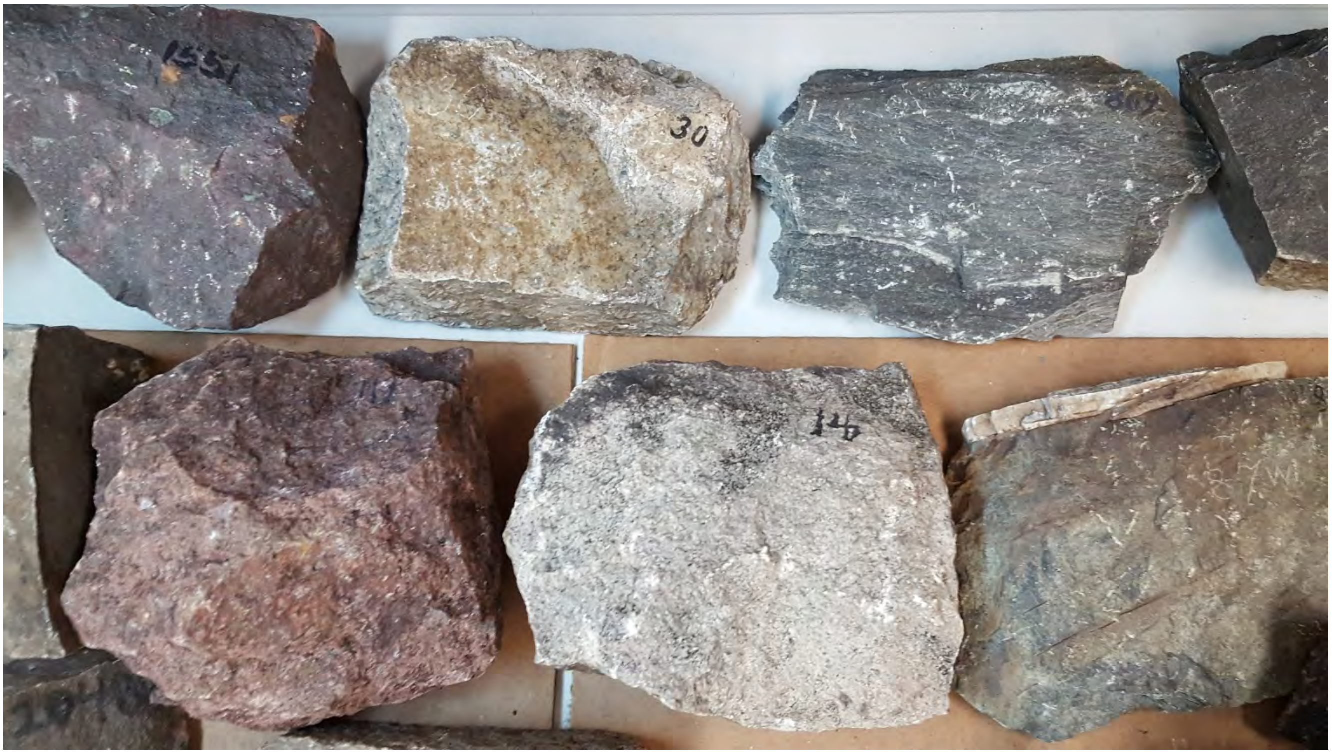
Black paint with pink numbers ending with an E

Pink numbers ending with a letter

Number ending with an H

White paint with green numbers

Blue numbers



Black numbers

Red numbers


Green numbers


Circular white labels

Figure 2.5 Examples of filled Winchell crates; the total of 14 was revised to 20, after all rocks were placed in crates rather than a mix of container types

Figure 2.6 Winchell crates; the revised total was 20


5/14
NEWTON HORACE
WINCHELL
Number 5/14
ending
with an H
NEWTON HORACE
WINCHELL
Number 6/14
ending
with an H
NEWTON HORACE
WINCHELL
Number 7/14
ending
with an H
NEWTON HORACE
WINCHELL
White paint 8/14
with green
numbers


NEWTON HORACE
WINCHELL
9/20
Blue numbers 9/14
NEWTON HORACE
WINCHELL
Blae numbers 10/14
NEWTON HORACE
WINCHELL
Blue numbers 11/14
NEWTON HORACE
WINCHELL
Black numbers 12/14


Black numbers 13/14
NEWTON HORACE WINCHELL
13/20
Black numbers 14/14
NEWTON HORACE WINCHELL
14/20
NEWTON HORACE WINCHELL
•Red numbers
•Green numbers
•Green numbers
16/20
NEWTON HORACE WINCHELL
•Box #12 Winchell 128-231
•A Winchell 7 #973H08 #1-36A
•Pink numbers


NEWTON HORACE WINCHELL
7978-7999
Box61 Sparr-2355
Pink numbers with on S
Pink numbers with a letter
NEWTON HORACE WINCHELL
19/20
A Winchell 473-808
Box #12 Winchell 128-231
Box #11 Winchell 123-231
NEWTON HORACE WINCHELL
NEWTON HORACE WINCHELL
Box #11 Winchell 123-231
(circular white labels)
circular white labels

Figure 2.7 Roland Mohr Biwabik and Gunflint stromatolite collection, now stored at UMN Tate

Figure 2.8 Air Force cores from Minnesota, referred to as DV Cores (Crisp, R. W. and Saucier, K. L., 1970, Tests of Rock Cores, Duluth-Vermillion Study Area, Minnesota, US Army Engineer Waterways Experiment Station, Miscellaneous Paper C-70-9)

Figure 2.9 Shipping, April 1, 2019; ‘the crates’ are on the left in the foreground, and the newly constructed Winchell crates are on the right

Figure 2.10 Count of Winchell rocks by year

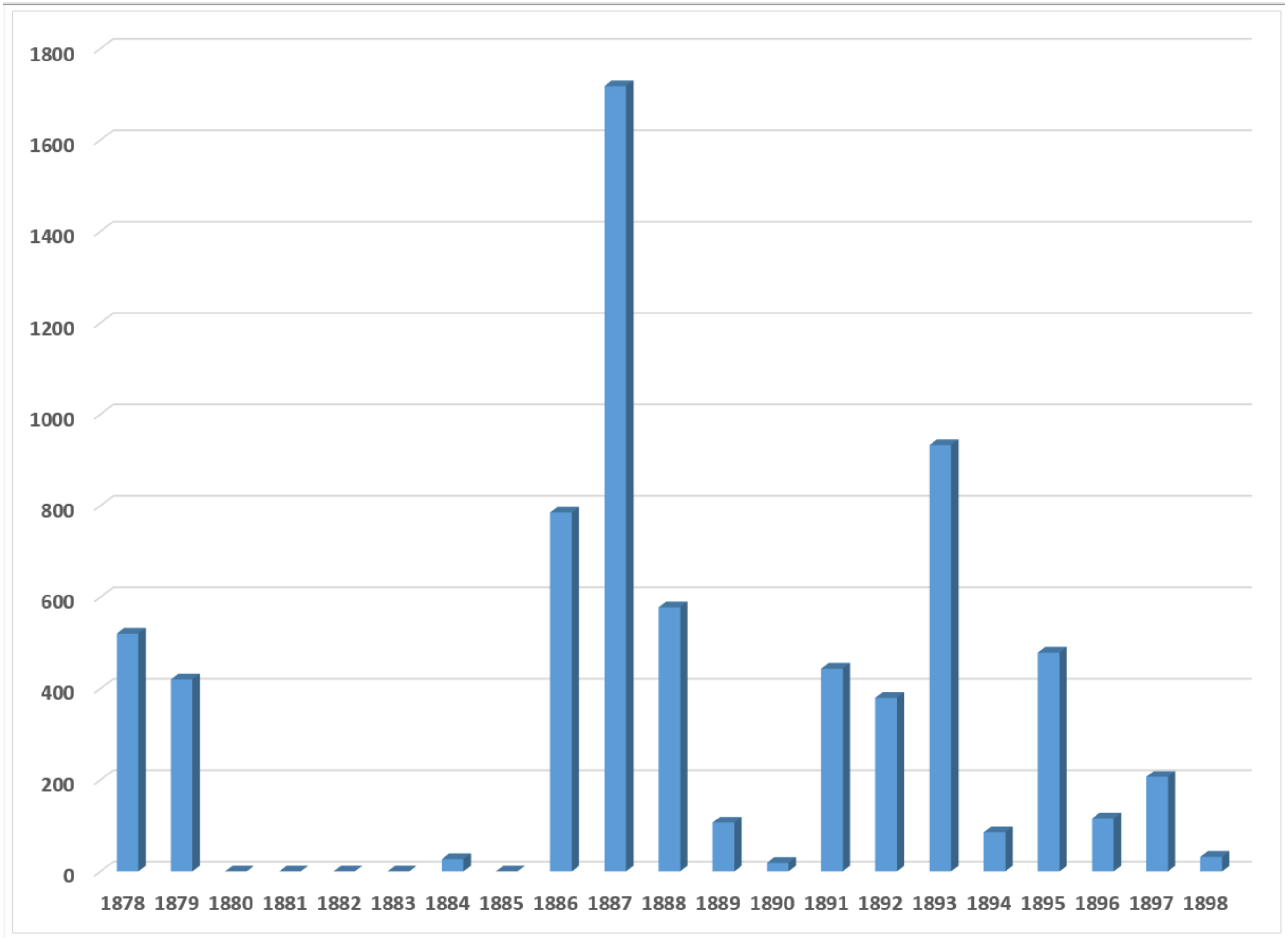


Figure 2.11 Estimated location for Winchell rocks. The map is truncated, thus excluding specimens located at Sioux Falls, Ontario north of Lake Huron, and New York State

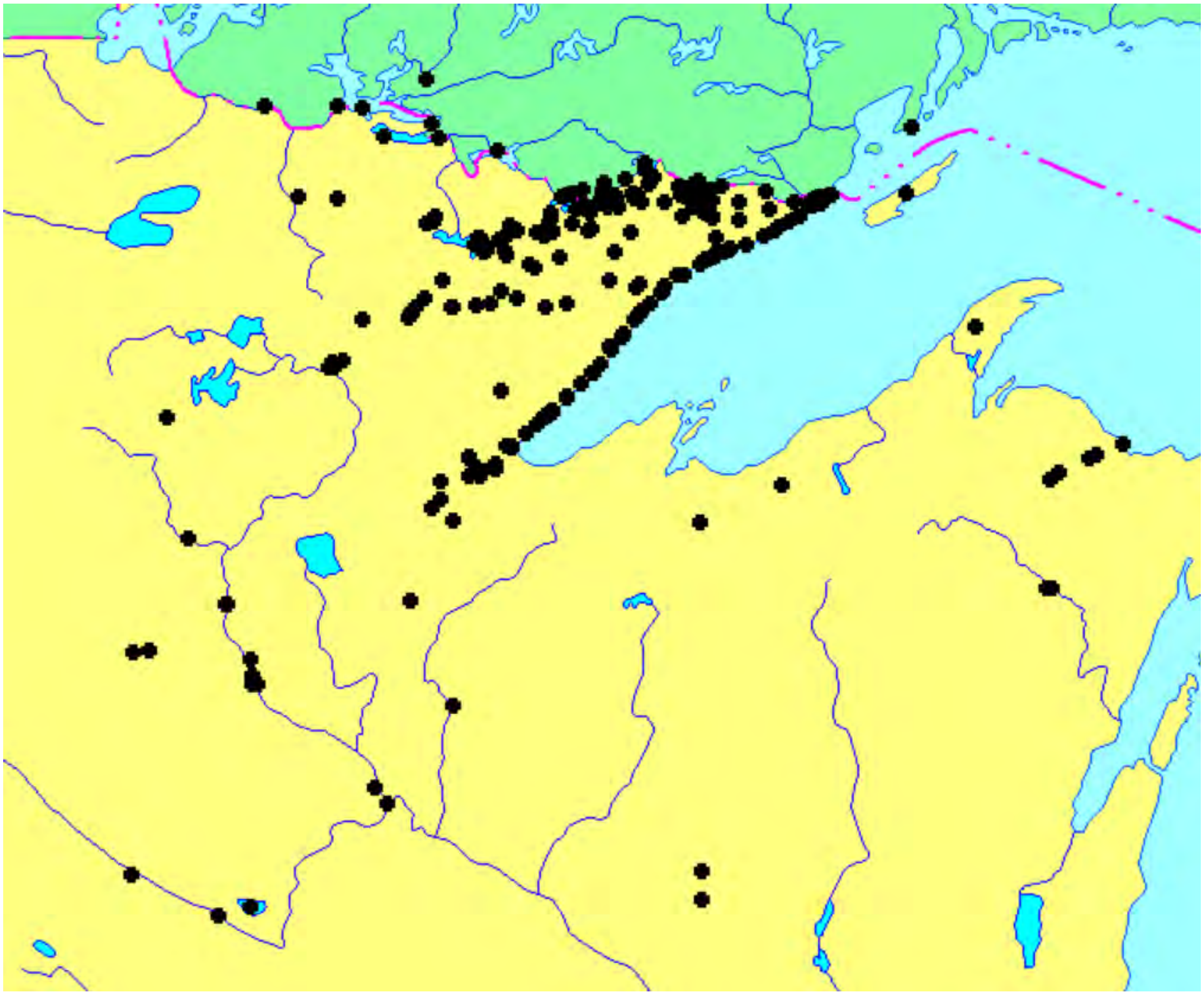


Table 2.1 Source of Winchell rock records

Annual Report	Geologist	Start page	End page	Start ID	End ID	Count	Total #'s
MGS_AR_9.pdf	NH Winchell	11	114	1	442	442	442
MGS_AR_10.pdf	NH Winchell	9	122	443	836	394	836
MGS_AR_13.pdf	NH Winchell	39	40	837	863	27	863
MGS_AR_15.pdf	A Winchell	19	171	1	358	358	1221
MGS_AR_15.pdf	NH Winchell	386	398	864	1109	246	1467
MGS_AR_15.pdf	ME Wadsworth	398	399	1110	1140	31	1498
MGS_AR_15.pdf	HV Winchell	413	419	1	74	74	1572
MGS_AR_16.pdf	NH Winchell	114	129	1148	1500	353	1925
MGS_AR_16.pdf	A Winchell	369	387	1	990	990	2915
MGS_AR_16.pdf	HV Winchell	464	478	75	353	279	3194
MGS_AR_17.pdf	HV Winchell	135	144	354	542	189	3383
MGS_AR_17.pdf	US Grant	202	215	1	298	298	3681
MGS_AR_18.pdf	NH Winchell	59	63	1501	1606	106	3787
MGS_AR_20.pdf	NH Winchell	33	34	1607	1626	20	3807
MGS_AR_20.pdf	US Grant	96	110	299	734	436	4243
MGS_AR_21.pdf	US Grant	59	67	735	893	159	4402
MGS_AR_21.pdf	NH Winchell	153	160	1627	1785	159	4561
MGS_AR_22.pdf	NH Winchell	5	17	1786	1968	183	4744
MGS_AR_22.pdf	US Grant	79	86	894	1016	123	4867
MGS_AR_22.pdf	AD Meeds	87	89	1	46	46	4913
MGS_AR_22.pdf	JE Spurr	126	133	10	230	221	5134
MGS_AR_22.pdf	AH Elftman	181	189	1	288	288	5422
MGS_AR_23.pdf	US Grant	220	223	1017	1067	51	5473
MGS_AR_23.pdf	NH Winchell	238	240	1969	1979	11	5484
MGS_AR_24.pdf	NH Winchell	1	39	1980	2078	99	5583
MGS_AR_24.pdf	NH Winchell	39	84	2079	2280	202	5785
MGS_AR_24.pdf	US Grant	145	147	1068	1099	32	5817
MGS_AR_24.pdf	AH Elftman	150	170	289	767	479	6296

Table 2.2 Newton Horace Winchell rock crates

1. Red paint with dark numbers
2. Black paint with pink numbers ending with an E
3. Black paint with pink numbers ending with an E
4. Pink numbers ending with a letter
5. Number ending with an H
6. Number ending with an H
7. Number ending with an H
8. White paint with green numbers
9. Blue numbers
10. Blue numbers
11. Blue numbers
12. Black numbers
13. Black numbers
14. Black numbers
15. Red numbers, green numbers, green numbers
16. Box #12 Winchell 128-251; A Winchell 7 #973/408 #1-36A; Pink numbers
17. Box 41 Meed Inc 7978-7999 Box 61 Spurr – 2355 Box 61 Spurr 2355
18. Pink numbers with an S; Pink numbers with a letter; Pink numbers with an A
19. A Winchell 473-808; Box #12 Winchell 128-231; Box #11 Winchell 123-231
20. Box #11 Winchell 123-231; A Winchell #973H08 #1-36A (circular white labels)

Table 2.3 Observations by M. Jirsa and A. Block regarding specimens in each Winchell crate

Crate 1; Red paint with dark numbers

- A mix of intrusive, supracrustal, and metamorphic rocks; no gabbros; greenstone/granite; probably Archean, possibly Paleoproterozoic; likely Archean of NE or N Central MN
- 427 dk (dark) fg (fine-grained)
- 461 pink cg (coarse-grained)
- 632 dk fg
- 678 pink cg
- 200G pink fg
- 639 dk fg
- Additional examples of IDs: 727, 711, 673, 676, 716, 243G

Crates 2 & 3; Black paint with pink numbers ending with E

- Looks like North Shore Volcanic Group and a few intrusives
- 328E dk pink fg
- 516E dk fg
- 527E dk dense
- 391E dk fg
- 479E dk fg porphyry
- Additional examples of IDs: 318E, 328 E, 360 E, 391 E, 479 E, 504 E, 527 E, 528 E, 532 E, 575 E
- Elftman tub: 189E, 262E, 296E, 182E, 217E, 188E

A tub labelled Elftman had the above format

Crate 4; Pink numbers ending with a letter

- S numbers: Maybe Paleoproterozoic; e.g. granular iron formation; but a mix, some Archean, maybe east Mesabi
- Remainder: largely North Shore Volcanic, midcontinent rift rocks
- 130S dk fg
- 14 dk pink fg
- 167E dk fg
- 74D pink fg
- 23C pink mg
- 80B dk pink fg
- 71A gray fg
- Additional examples of IDs: 122S, 48S, 167E, 81E, 161E, 74C, 79C, 56, 33, 39D, 74D, 22B, 32B, 38A, 20A
- Sparr tub: 199S, 124S, 217S, 227S, 150S

A tub labelled Sparr had the above format, with an S
A tub labelled Meed had the above format, with an M

Crates 5, 6, & 7: Number ending with an H

- massive micaceous; phyllite, schists; seem to be higher grade metamorphism than is typical in MN
- 250H gabbro
- 184H anorthosite?
- 151H dk fg
- 447H G dk fg
- 13C H dk fg
- Additional examples of IDs: 121H, 496H, 543H, 145H A

Crate 8; White paint with green numbers

- North Shore & Archean; Duluth Complex; granular iron formation i.e. Paleoproterozoic; NE MN mix
- 758 pink mg
- 993 dk fg
- 736 gabbro
- 880 dk fg dense
- 1004 red
- Additional examples of IDs: 1003, 751, 919, 985, 749, 712, 844, 875, 864

Crates 9, 10, & 11; Blue numbers

- A N MN mix; doesn't seem foreign; includes Quetico, North Shore
- 799 pink cg
- 1518 pink cg
- 1250 dk fg
- 809 dk pink fg
- 740 dk fg platey
- Additional examples of IDs: 799, 1356, 195, 741, 1627
- Winchell tub: 150, 156, 147, 153, 210, 211, 208, 180, 195
- A Winchell tub: 22, 21

Crates 12, 13, & 14; Black numbers

- Possibly not MN; not seeing diagnostic MN rocks
- 22 grey schist?
- 1921 grey micaceous
- 213 pink cg/mg
- 289 banded pink/black
- 1703 dk pink vesicular
- Additional examples of IDs: 1974, 27, 1551, 30, 313, 1939, 1957

Crate 15; Red numbers

- ➢ Nothing diagnostic; perhaps from away from MN
- 8022 white mg
- 2596 grey mg
- 8019 grey mg
- Additional examples of IDs: 3388, 8030, 8024

Crate 15; Green numbers

- ➢ Archean; N MN mix
- 1056 pink mg
- 1053 grey mg
- 1097 quartzite?
- 174G pink cg
- 1062 grey mg

Additional examples of IDs: 1053, 28G, 16G, 1059, 1089

Crate 16 to 20; White circular label with fine print

- ➢ Conceivably Paleoproterozoic; Animikie and related rocks, maybe
- 827 dk fg platy
- 921 dk fg platy
- 660 dk fg platy
- 689 dk fg platy
- Additional examples of IDs: 827, 919, 958, 660, 927, 441
- A Winchell tub: 583, 512, 613, 985, 1073

A tub labelled A Winchell had the above format

Table 2.4 List of projects represented by the Pillsbury Hall crates

Crate contents added to the MGS Hand Sample database, with storage location indicated

- Beitsch, Gillis Lake Quad – DNR Hibbing
- Bor-ming Jahn, PhD – DNR Hibbing
- Eugene Perry, research – DNR Hibbing
- Jodi Milske Mystery Cave – Cave
- John Tabor Voyageurs National Park – Park
- Long Island Lake – DNR Hibbing
- Paul Weiblen Moose Lake – DNR Hibbing
- Phinney, Duluth Complex – DNR Hibbing
- Phinney, Little Gabbro, Gabbro, & Bald Eagle Lakes MN – DNR Hibbing
- Roland Mohr Biwabik and Gunflint Stromatolites – UMN Tate
- Warren Day, PhD – DNR Hibbing

Crates that remain in the possession of the Department

- Franklin Ortiz
- Hartman/Sloan Red Fleet Reservoir & Mowry paleontological evaluation
- John Gruner radioactive minerals
- Rama Murthy
- Kimball Forrest, Lik Deposit AK
- Rock Analysis Lab
- Steve Wiele

Crates that were added to the MGS database, repackaged, and moved to Hibbing in the early-2010s

- Eugene Perry
- Joel Renner
- John Gruner
- Mary John
- Phinney, Duluth Complex

CHAPTER THREE: Synthesis of readily available digital information for mineral deposits and occurrences in Minnesota, *D. Dahl, DNR*

Minnesota Department of Natural Resources – Lands and Minerals Division (DNR), in collaboration with the Minnesota Geological Survey (MGS) and the University of Minnesota's Natural Resources Research Institute (NRRI), compiled the location of mineral deposits and resources in Minnesota containing commodities designated by United States Geological Survey (USGS) to be Phase II critical minerals (aluminum, cobalt, graphite, lithium, niobium, platinum group metals, tantalum, tin, titanium, and tungsten).

In Minnesota, deposits and resources having publicly available grade and tonnage estimates for one or more Phase II critical minerals correspond to the known nonferrous metallic base metal mineral deposits in the state. This compilation was requested by USGS, via its Earth Mapping Resources Initiative program (Earth MRI), and the National Geological and Geophysical Data Preservation Project (NGGDPP). The request was to assemble in a provided format publicly available mineral deposit information for Phase II critical minerals in the state, to be included in USGS's USMIN mineral occurrence database project.

A total of ten deposits and resources has been identified as having publicly available grade and tonnage estimates that qualify them to be listed as mineral deposits for their occurrence status. The publicly available grade and tonnage estimates for nine of the ten deposits are in the form of current reporting code resource estimates, as are found in formats such as Canadian National Instrument NI 43-101 technical reports. The Water Hen deposit grade and tonnage estimate is from a publicly available historical report contained in Minnesota DNR's mineral exploration archives. The Spruce Road deposit, while reporting a modern grade and tonnage estimate for copper and nickel, does not have corresponding assay work to establish cobalt or platinum group metal grades. The Spruce Road deposit is included in the list, however, due to its location adjacent to deposits that do report Phase II critical minerals, and due to its similar geologic setting and geologic history. All of the known nonferrous metallic mineral deposits discovered to date in Minnesota are located in the northeastern part of the state.

Figure 3.1 shows the distribution of these nonferrous metallic mineral deposits in Minnesota as of December, 2019.

A spreadsheet and GIS file accompany this report. The spreadsheet includes compiled deposit information, and is formatted for submission to the USGS Earth MRI program for the USMIN database. The data also are provided as a GIS point file in ESRI shapefile format. A tabular summary of the spreadsheet and GIS file information is shown in Table 3.1. Table 3.1 shows reported estimates for inferred resources separate from measured and indicated resources, in keeping with reporting code guidelines. TMM on the table stands for Twin Metals Minnesota.

An additional inventory of mineral occurrences in Minnesota, that do not qualify as having deposit status with a grade-tonnage estimate, including mineralized zones, mineralized intercepts, and mineral showings, is currently being compiled from archived publicly available exploration records as part of an in-house DNR project. This inventory of mineral occurrence below deposit level will become available for use as that work proceeds.

Accompanying digital file:

Minnesota nonferrous mineral deposits (MinnesotaNonferrousMineralDeposits.zip)

Table 3.1 Summary of Minnesota Nonferrous Metallic Mineral Deposits and Resources

Site Name and Date	UTM_East	UTM_North	Commodity	Resource	Units	Resource Type and Source
Mesaba - 2019	582758	5277200	Cu, Ni, Co, PGM	1578.2	Mt	Measured and Indicated - Teck
Mesaba - 2019	582758	5277200	Cu, Ni, Co, PGM	1461.9	Mt	Inferred - Teck
Tamarack North - 2018	490750	5168700	Ni, Cu, Co, PGM	3.6	Mt	Indicated - Talon Metals
Tamarack North - 2018	490750	5168700	Ni, Cu, Co, PGM	4.4	Mt	Inferred - Talon Metals
Northmet - 2018	577676	5272361	Cu, Ni, Co, PGM	649.3	Mt	Measured and Indicated - Polymet
Northmet - 2018	577676	5272361	Cu, Ni, Co, PGM	508.9	Mt	Inferred - Polymet
Maturi - 2014	596754	5293027	Cu, Ni, Co, PGM	1069.0	Mt	Measured and Indicated - TMM
Maturi - 2014	596754	5293027	Cu, Ni, Co, PGM	562.0	Mt	Inferred - Duluth Metals/TMM
Maturi Southwest - 2014	590964	5293334	Cu, Ni, Co, PGM	103.0	Mt	Indicated - Duluth Metals/TMM
Maturi Southwest - 2014	590964	5293334	Cu, Ni, Co, PGM	32.0	Mt	Inferred - Duluth Metals/TMM
Birch Lake - 2014	590662	5283325	Cu, Ni, Co, PGM	100.0	Mt	Indicated - Duluth Metals/TMM
Birch Lake - 2014	590662	5283325	Cu, Ni, Co, PGM	239.0	Mt	Inferred - Duluth Metals/TMM
Longnose- 2011	572200	5268300	TiO2	58.1	Mt	Indicated - Cardero Resource Corp.
Longnose- 2011	572200	5268300	TiO2	65.3	Mt	Inferred - Cardero Resource Corp.
TiTac - 2011	568000	5228000	TiO2	45.0	Mt	Inferred - Cardero Resource Corp.
Spruce Road - 2010	599775	5298915		480.0	Mt	Inferred - Duluth Metals/TMM
Water Hen - 1967/1958	566695	5249065	Ti, Graphite	4.8	Mt	Leased by Encampment Resources

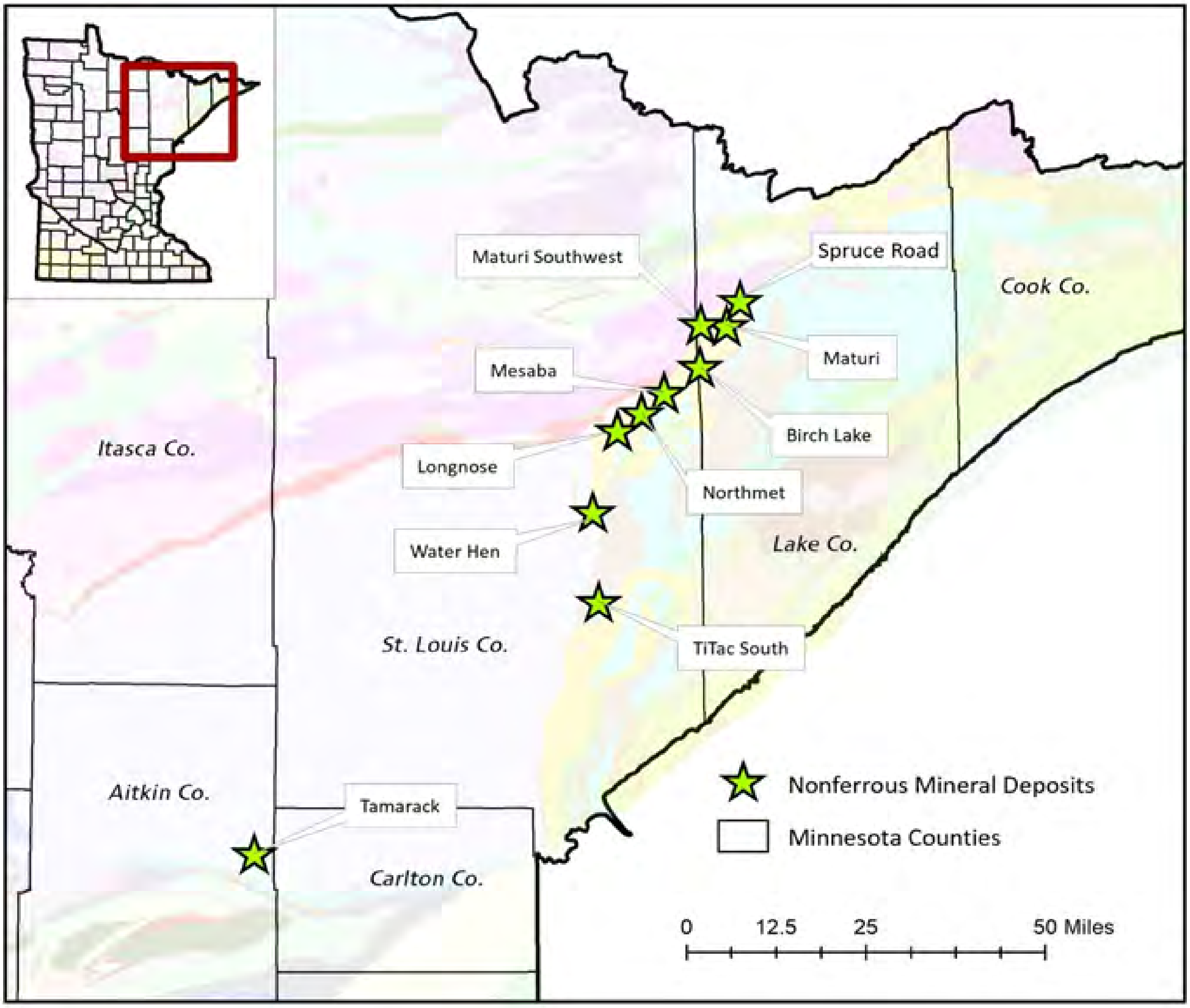


Figure 3.1: Nonferrous metallic mineral deposits in Minnesota. Deposit information extract as of 12/14/2019, Minnesota Department of Natural Resources, Lands and Minerals Division. Bedrock geology from Minnesota Geological Survey Map S-21.

CHAPTER FOUR: Digital database for publicly available drill core in Minnesota, *D. Dahl, DNR*

As part of the 2019-2020 NGGDPP award to Minnesota, the Minnesota Department of Natural Resources (DNR) – Lands and Minerals Division was asked to compile a list of publicly available drill cores housed at the DNR drill core library repository in Hibbing MN. The DNR core library facility serves as the single public repository for drill core in the state. Various other types of geologic materials acquired from within the state also are stored at the facility. To simplify this discussion, cuttings collected from non-cored boreholes housed at the drill core library are included. Most cuttings in MN are stored at MGS, however, but a few are at DNR. MGS holds a database for this large cuttings collection, and also holds a large database for water well records.

Currently, the drill core library holds over 3 million linear feet of core in three core storage buildings. The cores and other geologic materials at the library have been obtained as a result of exploratory, investigative, research, or other activities. Storage of these cored materials, as well as free public access for examination of core is directed by Minnesota law, which mandates the submission to the DNR of at least one quarter diameter of all exploratory boring cores, or cuttings if not cored, to serve as an archive sample of materials encountered, and to be available for additional research and mapping purposes. Figures 4.1 and 4.2 show the distribution of publicly available drill core materials housed at the DNR drill core library in Hibbing, Minnesota.

Since large portions of Minnesota are covered by glacial drift or sedimentary rocks, drill core samples of buried Precambrian and other bedrock units are the only available ground truth for geologic mapping, research and modeling activities across large portions of the state. Drill cores housed at the drill core library range in geologic age from Archean to Holocene, with completion dates ranging from 1905 for some donated core samples from the Gunflint Trail area to 2018 for submissions from recent scientific geologic mapping investigations.

Drill hole/drill core database entries associated with publicly available in-house core holdings at the drill core library correspond to 8,290 records of borehole core or cuttings submissions. Of these:

- 2,996 were drilled during ferrous metallic mineral explorations
- 2,149 were drilled during geotechnical investigations
- 2,038 were drilled during nonferrous metallic mineral explorations
- 931 were drilled during scientific research projects
- 126 were drilled during energy mineral explorations focused on uranium
- 47 were drilled during industrial minerals explorations
- 3 were drilled during hydrocarbon explorations

The total of 8,290 records of publicly available drill core holdings is derived as follows:

- Of 11,592 records in the existing database, 2,159 records are found to be inventory of known drill holes that do not have core or cuttings holdings on site at the drill core library. Of the 2,159 entries not having in-house holdings, 1,747 of the records are associated with active exploration areas where boreholes are known to exist but core is not yet required to be submitted to the State or are associated with drillhole entries that had no core materials submitted. The other 412 entries are associated with Department of Transportation geotechnical boring locations having no corresponding core, or other scientific or geotechnical drilling locations having no record of associated core submissions.
- Of the 9,433 drill hole/drill core records remaining after removing no-holdings entries, 460 records are found to not have coordinate locations listed. The majority of these 460 records are associated with iron explorations on the Mesabi iron range. Additional audit and examination of submission records is needed to establish the spatial location of these cores for research and mapping purposes.
- Of the 8,973 drill hole/drill core records remaining after removing entries having no spatial location, 683 records were found to be associated with entries currently classified as nonpublic core, or whose status is questionable about nonpublic status, leaving 8,290 records of publicly available core.

Digital files: Minnesota public drill core (MinnesotaPublicDrillCore.zip)

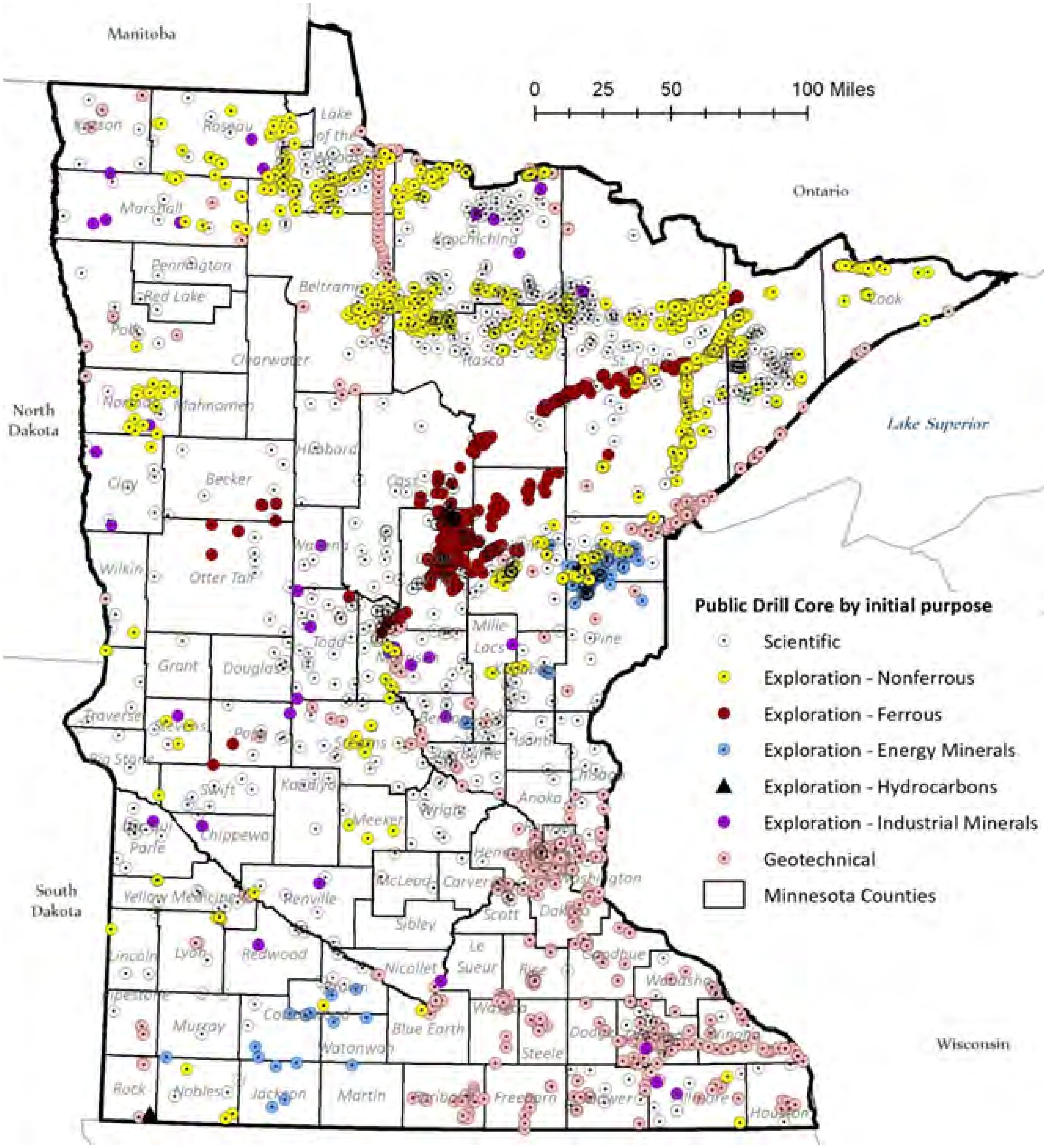


Figure 4.1: Distribution and origin of public drill core available in the DNR Drill Core Library. Drill core information extract as of 12/14/2019. Minnesota Department of Natural Resources Lands and Minerals Division.

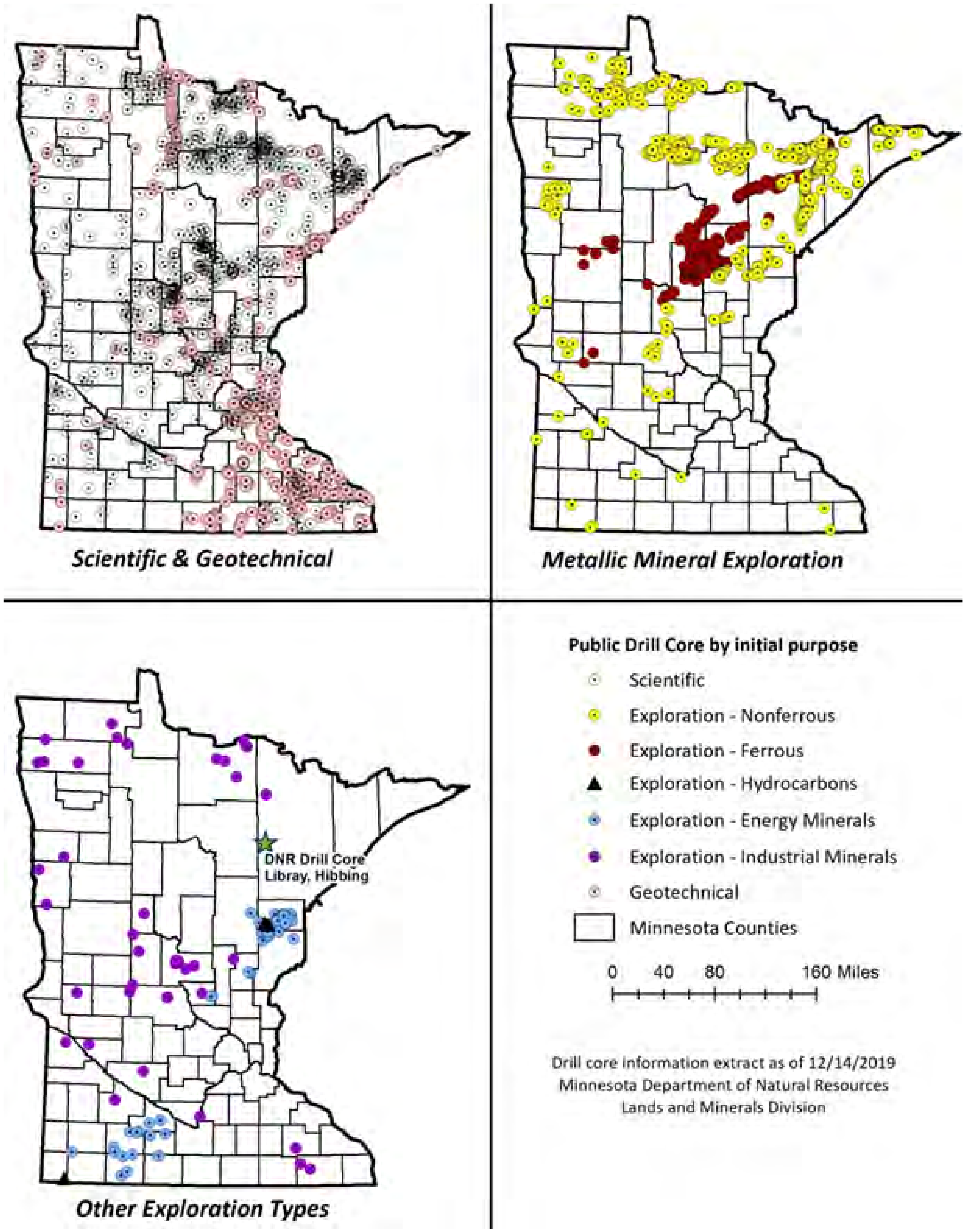


Figure 4.2: Varying distributions of core available in the DNR Drill Core Library

CHAPTER FIVE: Digital GIS database to indicate ongoing mineral exploration activities based on the extent of active and historical nonferrous mineral leases in Minnesota, *D. Dahl, DNR*

As part of the 2019-2020 NGGDPP award to Minnesota, the Minnesota Department of Natural Resources (DNR) – Lands and Minerals Division was asked to compile mineral exploration areas associated with Phase II critical minerals.

Interest in exploring Minnesota's Precambrian bedrock terranes has occurred since the early 1800's, in part due to discoveries of copper and iron in Michigan's upper-peninsula. Early government reconnaissance expeditions into present-day Minnesota reach back more than 50 years prior to statehood in 1858. Minor gold rushes occurred in ~1865 in the vicinity of Lake Vermilion, and ~1893 at Rainy Lake. Iron occurrences noted in these early gold explorations were investigated by several parties, and dip needle iron exploration records from the 1870's, and perhaps earlier, are found for Minnesota's Vermilion, Cuyuna and Mesabi iron districts. State leasing programs for iron exploration and development have been in place since the late 1800's. The State leasing program for nonferrous metallic mineral exploration and development has been in place since 1966.

Minnesota's bedrock and surficial materials thus are a diverse geological landscape that has attracted exploration interest for a wide variety of ferrous, nonferrous, industrial mineral and surficial deposits. The mineral deposit potential across the state, even after more than 150 years of exploration activity, is still only partly known due largely to the logistical difficulty of exploring bedrock under surficial materials, forests and wetlands.

These formations and surficial materials have had complex histories. Some assemblages have been subjected to multiple geologic environmental settings over time, and each combination of materials and geologic settings has presented a unique opportunity to concentrate, accumulate and preserve mineral deposits. Some settings have been favorable for deposition of iron-bearing ferrous materials, whereas some have been favorable for deposition of nonferrous metallic or industrial mineral deposits. Some settings have been favorable for deposition of surficial deposits. This section focuses on areas in Minnesota where episodes of nonferrous metallic mineral exploration have taken place, and highlights areas of active, as of December 2019, private nonferrous mineral exploration investment on state-owned leaseholds. In Minnesota, areas favorable for Phase II critical mineral resources occurrence are associated with areas favorable for nonferrous mineral occurrence.

In focusing on nonferrous metallic mineral exploration, we recognize but defer discussion of other Minnesota mineral resources and occurrences: 1) ferrous metallic minerals including Lake Superior type banded iron and manganese-bearing iron formations, Algoma type iron formations such as at Soudan and Ely, and Phanerozoic sedimentary iron deposits such as at Fillmore County; 2) non-metallic industrial minerals such as silica sand, kaolin clay, limestone, diamond, etc.); 3) construction aggregate materials such as sand, gravel, crushed stone, decorative stone, and marl); 4) dimension stone materials such as appropriate granite, gabbroic rocks, and limestones; 5) energy minerals, i.e. uranium; 6) and peat resources used for horticultural and energy purposes.

Nonferrous metallic mineral exploration other than the early gold rushes in Minnesota are largely an outgrowth of iron exploration that traced dip needle magnetic anomalies in greenstone belts, the Duluth complex, and other Minnesota geologic terranes. Early airborne magnetic surveys by USGS after World War II, with 1 mile line spacing and 1,000 foot terrain clearance, more fully outlined the major Precambrian geologic terranes in the state and set the stage for regional and detailed base metal exploration on federal and privately owned lands in the 1950's, and on state, federal and private lands in the 1960's and 1970's.

Discovery of the Kidd Creek copper-zinc deposit in Ontario in 1963, via airborne electromagnetic survey and follow up drilling of geophysical anomalies, launched an extended episode of similar exploration programs both globally and in Minnesota, conducted by established mineral explorers and also by new exploration firms established by petroleum companies who had extensive experience in geophysical exploration methods. Large regional private exploration programs conducted by these companies in Minnesota established the presence of mineral deposits, mineral zones, mineral intercepts and mineral showings of copper, nickel, cobalt, titanium, zinc, lead, other base metals; and gold, silver, and platinum group element precious metals.

Airborne geophysical and drill sampling methods were also deployed in Minnesota in the 1970's to explore for uranium, which had seen a 10-fold increase in spot metal price. These surveys, primarily in east-central and southwestern Minnesota, did not produce substantial mineral occurrence discoveries before the collapse of the uranium market in 1979 following the Three Mile Island incident in Pennsylvania. But this work did produce extensive reusable and publicly available geophysical and drill sample data applicable to future geologic mapping and nonferrous mineral exploration.

Minnesota's nonferrous metallic mineral leasing program for state-owned lands, and associated statutes, rules, policies and procedures have been in existence since 1966, spurred by discovery of low grade copper-nickel deposits on nearby federal and private lands in northeastern Minnesota in the 1950's.

The State of Minnesota owns about 25% of the mineral rights in the state, primarily associated with educational trust lands, acquired natural resource lands, and state-owned tax forfeit and consolidated conservation lands.

Mineral exploration and leasing are ongoing activities in Minnesota. Most state-owned mineral rights are located in the northern half of the state, and the cumulative footprint of leased state lands for nonferrous metallic minerals gives a reasonable indication of where historic exploration trends have taken place and give some indication of places where future exploration activities might be expected.

Figure 5.1 shows this distribution of active and historic nonferrous metallic mineral exploration areas in Minnesota, as of December 2019, using the leasing footprint on extensive State owned lands as a proxy for that of overall exploration areas.

Figure 5.1 does not display an extent for mineral leasing related to uranium exploration, since Minnesota has not had a statutory or rule mechanism for leasing of state-owned lands for uranium exploration or development. Mineral leasing during the uranium exploration episode in the 1970's was conducted entirely on privately owned lands, so there is no area of state owned lands to serve as a proxy for uranium exploration areas.

Digital files: Minnesota nonferrous leasing (StateOfMinnesotaNonferrousLeasing.zip)

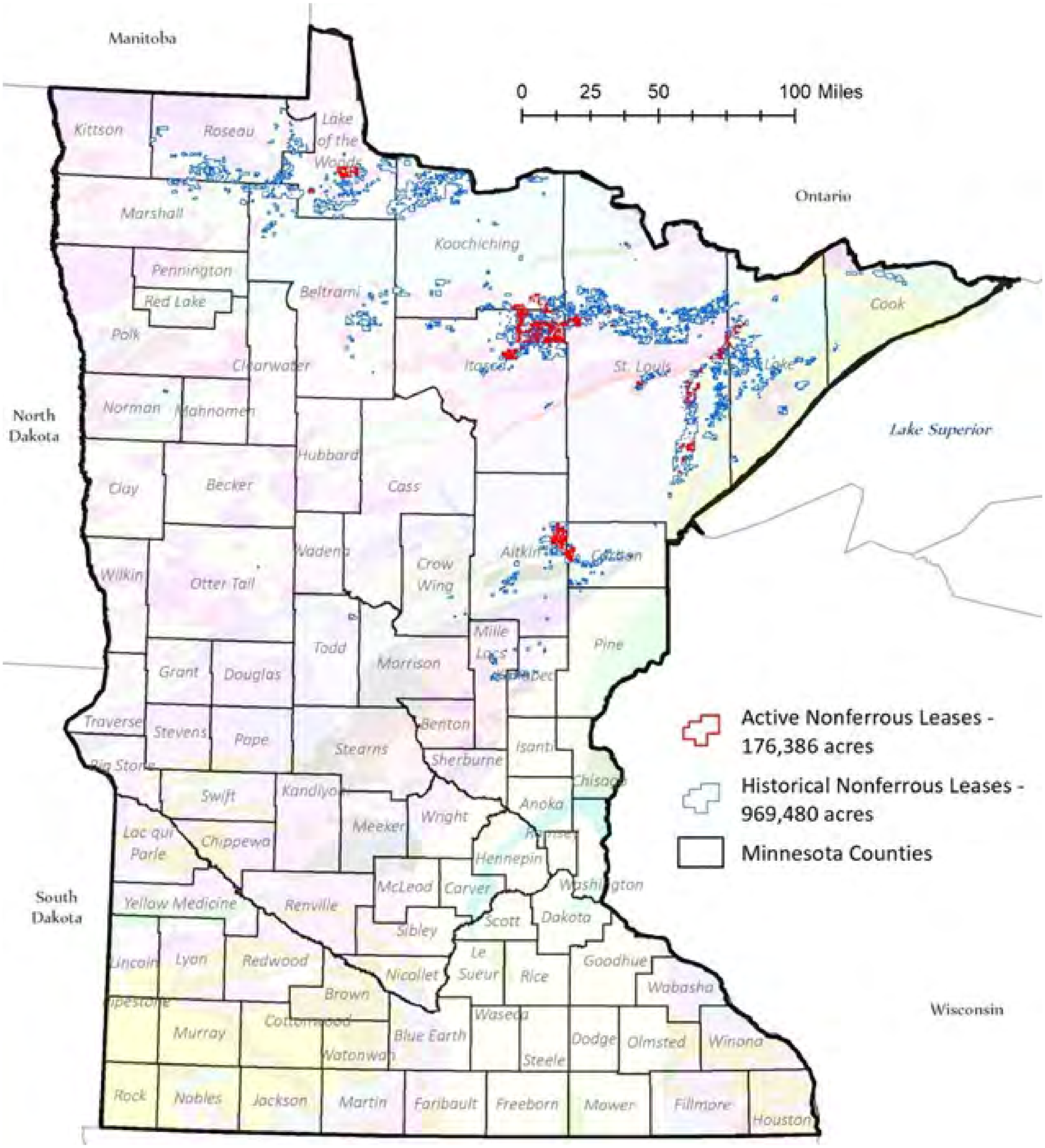


Figure 5.1: Nonferrous metallic mineral leasing on State owned land. Leasing information extract as of 12/14/2019, Minnesota Department of Natural Resources, Lands and Minerals Division. Bedrock geology from Minnesota Geological Survey Map S-21.

CHAPTER SIX: A description and listing of published research specific to Minnesota that supports inference of mineral potential based on geological mapping, *G. Hudak, NRRI*

In relation to FY 2019 NGGDPP funding to Minnesota, as part of Priority 3, the Natural Resources Research Institute (NRRI) was subcontracted by the Minnesota Geological Survey to prepare a brief description of published research specific to Minnesota that supports inference of mineral potential on the basis of geological mapping, and a bibliography listing references for published literature on this topic. The NRRI provided matching funding to complete the work from the University of Minnesota Permanent University Trust Fund.

The USGS recently developed a new minerals system approach for critical minerals inventory, research and assessment (https://www.usgs.gov/energy-and-minerals/mineral-resources-program/science/systems-approach-critical-minerals-inventory?qt-science_center_objects=0#qt-science_center_objects; Hostra, 2019). The following bibliography is organized utilizing this minerals system classification scheme.

As Minnesota has a preserved geologic history that spans greater than 3.6 billion years, and as a wide variety of geological processes has been active over this geological history, potential exists in many of the mineral systems, including Chemical Weathering, Placer, Meteoric Recharge, Marine Chemocline, Volcanogenic Seafloor, Orogenic, Metamorphic, IOA-IOCG, and Mafic Magmatic.

In addition, a short bibliography of potential By-Products/Recycling resources has been included with this bibliography.

Reference

Hostra, A., 2019, Mineral Systems Approach for Earth MRI: Public Presentation at the USGS Earth MRI Workshop, Reston, VA, October 22, 2019.

ACCOMPANYING DOCUMENT: Minnesota research on mineral potential

Hudak, G.J. 2020. A bibliography of published research in Minnesota related to the state’s mineral potential. Natural Resources Research Institute, University of Minnesota Duluth, Technical Summary Report NRRI/TSR-2020/13, 138 p.

CHAPTER SEVEN: Modelled grids depicting current knowledge on: 1) depth to bedrock, 2) depth to pre-Mesozoic, 3) depth to Precambrian, and 4) depth to basement; supplement to MGS Mapping Database D-03, Depth to Bedrock, *V.W. Chandler*, *with Minnesota Geological Survey Staff*

Overview: In relation to FY19 NGGDPP funding, MGS staff assembled raster grids depicting current knowledge for elevation of the bedrock surface, the top of pre-Mesozoic, the top of Precambrian, and the top of basement. The elevation surfaces may be used to obtain depth to grids, by subtracting the elevation surface from the land or lake surface. Basement is the top of structurally complex Precambrian rocks, under rocks such as Phanerozoic and Proterozoic basins represented by 2D map polygons whose thickness can be determined, and thus that can be removed as a layer. As proposed, the depth to bedrock map is the most recently released version. The pre-Mesozoic surface required little modification from preexisting work, although much effort in geophysical modeling and drillhole interpretation was required to produce the Precambrian and basement surfaces.

Bedrock surface: The top of bedrock in Minnesota is defined as the interface between sediments of Quaternary age, and underlying deposits regarded in most cases as rock, although in some areas, principally Cretaceous sediments or Cretaceous and older weathering profiles, the rocks are poorly lithified, or deeply weathered. Depth to bedrock is thus regarded as the thickness of post-Cretaceous sediments plus bathymetry, and is calculated by subtracting the bedrock elevation from elevation of the land surface.

MGS practices for bedrock topography and depth to bedrock mapping were summarized by Setterholm (2019). Bedrock topography and land surface elevation are equivalent in areas of bedrock outcrop, which are extensive in northeastern and southeastern Minnesota, as well as in and near the Minnesota River Valley, and a few other areas. In sediment-covered areas, elevation of the bedrock surface is mapped primarily using data from wells along with scientific and exploration drill holes, supplemented by geophysical soundings. Deep wells that do not reach bedrock provide a minimum depth to bedrock.

Bedrock elevation contours generally are drawn as an interpretive map by a geologist. The contour mapping takes into account data density, susceptibility to erosion of bedrock units, and interpretation of geomorphology of the surface, whether due to glacial or fluvial erosion, and/or karst, although interpretation of a preglacial fluvial landscape is favored.

Over much of the state, a 50-foot bedrock contour interval has been used, although in areas with many wells, 25 foot intervals have been added. The accuracy of the wellhead elevations from the well records is about +/- 5 feet, because many have been obtained from points on topographic maps with 10-foot contours. Once an area, usually a County, has been contoured, a bedrock elevation raster is generated, with a cell size of 30 meters. Due to the 50 foot contour interval, the bedrock surface inevitably is smoother than a land surface DEM. When the bedrock surface is subtracted to obtain depth to bedrock and thus sediment thickness, detail is inherited from the land surface topography. Most of the contour lines are derived from County 1:100,000 scale mapping and have been edged matched in many areas. Where contours are not available, water well points that provide a bedrock elevation were used as auxiliary data. Where wells are not available, in areas outside of Atlas coverage, outcrop polygon centroids were created, assigned surface elevations and used as point data for the gridding.

In southeastern Minnesota, bedrock topography shows an integrated drainage pattern with deep and buried preglacial channels incised into Paleozoic limestones, shales and sandstones. Elsewhere, the bedrock surface reflects the more resistant nature of igneous and metamorphic rocks, but indications point to multiple generations of incision and weathering. Thickness of Quaternary sediments ranges from 0 to over 1,000 feet.

Olsen and Mossler (1982) produced a statewide depth to bedrock contour map from limited water well data available at that time. The first grids for bedrock elevation and depth to bedrock were later produced by Lively et al. (2006), with the intent of regularly updating the database as water well data accumulated and County Atlas products provided interpreted bedrock elevation maps. The surfaces were updated in 2010 (Jirsa et al., 2010), and another update was released on the MGS web site in 2016.

As proposed, the 2016 version of the bedrock surface, with substantial updating, is included with this submission. A further revision is scheduled to be released later in 2020, due to support from the USGS Great Lakes Geologic Mapping Coalition (GLGMC). This pending release will incorporate point drift thickness data from about 200 passive seismic soundings (Chandler and Lively, 2016) in data-poor regions of northern and northwestern Minnesota, along with other updates that are available. This work has provided an opportunity to add significant data to the passive seismic soundings database for Minnesota. Experience, and continued refinement of passive seismic calibration data with depth to bedrock based on new drilling, will allow progressive maturation of the method and its application. In addition, a map of the bedrock surface for the portion of Lake Superior that is within Minnesota was been compiled from the literature (Wold et al., 1982) and included with this submission.

Pre-Mesozoic: Mesozoic strata that occur across Minnesota, primarily in the southwest, consist of widely varying clastic deposits, along with marl and minor lignite, that were deposited in marine and non-marine settings, likely in the Albian to Campanian portion of the Cretaceous (Jirsa et al., 2011). In far northwestern Minnesota, Jurassic deposits known as the Hallock Red Beds occur, including shale, limestone, dolostone, siltstone, and sandstone. The thickness and distribution of these Jurassic deposits is very poorly known.

The elevation of the contact between Mesozoic strata and underlying rocks was mapped by Dale Setterholm of MGS during construction of the most recent bedrock geology map of Minnesota (Jirsa et al., 2011). This was primarily based on recognition of the lower contact of the Mesozoic in water well records, and gridding of the resulting data. Because the deposits are patchy, an isopach was created from the contoured top and base, and the deposits were disregarded where inferred to be less than 25 feet (8 meters) thick. By subtracting Mesozoic thickness from the bedrock surface, a map was obtained for elevation of top of Mesozoic. Some updates to the Mesozoic strata have been made as part of County Atlas projects, and these are included in the current grid.

Precambrian: In areas beyond the extent of Phanerozoic rock, where the Precambrian is at the bedrock surface, data for bedrock topography was used for top of Precambrian. In areas of Mesozoic cover, where Paleozoic strata are lacking, data from the pre-Mesozoic surface was used for top of Precambrian. For areas under Paleozoic cover, top of Precambrian was obtained by digitizing contours from a Precambrian basement map for the northern midcontinent (Sims, 1990). This Precambrian surface was adjusted where newer data were available.

Basement: Basement is here defined as the top of more structurally complex rocks that are under less complex rocks outlined in 1:500,000 mapping as 2D polygons whose thickness can be mapped, and thus that can be removed as layers. Within the Precambrian, these layers consist of Proterozoic basins (Jirsa and others, 2011). This effort represented entirely new mapping in developing the thickness of the layers and for mapping of the geology under the layers. The Precambrian strata with mappable thickness include the Animikie Group slates and associated rocks, Sioux Quartzite, North Shore Volcanic/Duluth Complex, and late Precambrian sedimentary basins of the Midcontinent Rift system.

Elevation of basement was derived from limited drillhole data, along with extensive geophysical modelling that incorporated work by Chandler (2008), which had in turn incorporated preceding work. The geophysical modelling initially included Euler elevation analysis for magnetic basement, cross section gravity models, and alternative magnetic models where Euler analysis was less effective. Inferences from this work were then hand contoured, followed by iteration with the Euler solutions and magnetic and gravity modeling. The resulting contours for elevation of basement were trimmed to the basin outline, and added to the Precambrian surface grid to produce a top of basement. Prior to making a basement grid, the outlines of the basins were converted to points, and elevations extracted from the Precambrian surface to establish an edge for each basin.

References:

Chandler, V. W., 2008, Extent and Thickness of Deep Sedimentary Rocks in the Upper Midwest: Geophysical Inferences, in: Thorleifson, L.H., editor, Potential Capacity for Geologic Carbon Sequestration in the Midcontinent Rift System in Minnesota, Minnesota Geological Survey, Open File Report OFR-08-01, p. 56-76.

Chandler, V. W., and R. S. Lively, 2016, Utility of the horizontal-to-vertical spectral ratio passive seismic method for estimating thickness of Quaternary sediments in Minnesota and adjacent parts of Wisconsin, Interpretation, v. 4, no. 3, p. SH71–SH90.

Jirsa, M. A., Bauer, E. J., Boerboom, T. J., Chandler, V. W., Lively, R. S., Mossler, J. H., Runkel, A.C., Setterholm, D. R., 2010, Preliminary Bedrock Geologic Map of Minnesota. Minnesota Geological Survey Open File 10-02.

Jirsa, M. A., Boerboom, T. J., Chandler, V. W., Mossler, J. H., Runkel, A. C., Setterholm, D. R., 2011, Geologic Map of Minnesota-Bedrock Geology, Minnesota Geological Survey Map S-21, scale 1:500,000.

Lively, R. S., Bauer, E. J., and Chandler, V. W., 2006, Maps of Gridded Bedrock Elevation and Depth to Bedrock in Minnesota. Minnesota Geological Survey Open File 06-02.

Olsen, B. M., and Mossler, J. H., 1982, Geologic map of Minnesota, depth to bedrock. Minnesota Geological Survey Map S-14, scale 1:1,000,000

Setterholm, D. R., 2019, Geologic Atlas User's Guide: Using Geologic Maps and Databases for Resource Management and Planning, Minnesota Geological Survey, Open-File Report 12-1, 3rd edition, 29 p.

Sims, P. K., 1990, Precambrian basement map of the northern midcontinent, U.S.A., U.S. Geological Survey, Miscellaneous Investigations Series Map I-1853-A; scale 1:1,000,000.

Wold, R. J., Hutchinson, D. R., and Johnson, T. C., 1982, Topography and surficial structure of the Lake Superior bedrock as based on seismic reflection profiles, in Wold, R. J., and Hinze, W. J., Geology and tectonics of the Lake Superior basin: Geological Society of America Memoir 156, p.257-272

Digital files: Supplement to MGS Mapping Database D-03, Depth to Bedrock; ArcGis Online map package.

Raster cell size for each surface is 90m, to accommodate limitations of large rasters made in ESRI ArcMap. The depth units for bedrock, pre-Mesozoic and Precambrian are in feet. Depth units for the basement are meters, with a maximum of about 20 km. The land surface 30m DEM derived from LiDAR was resampled to a 90 m cell size to match the bedrock surface grids prior to evaluating the thickness.

Files include:
Minnesota depth to bedrock: dt_bdrk_90m_060220
Minnesota depth to pre-Mesozoic: dt_preMeso_90m_060220
Minnesota depth to Precambrian: dt_preCamb_90m_060220
Minnesota depth to basement: dt_basement_m_90m_060220

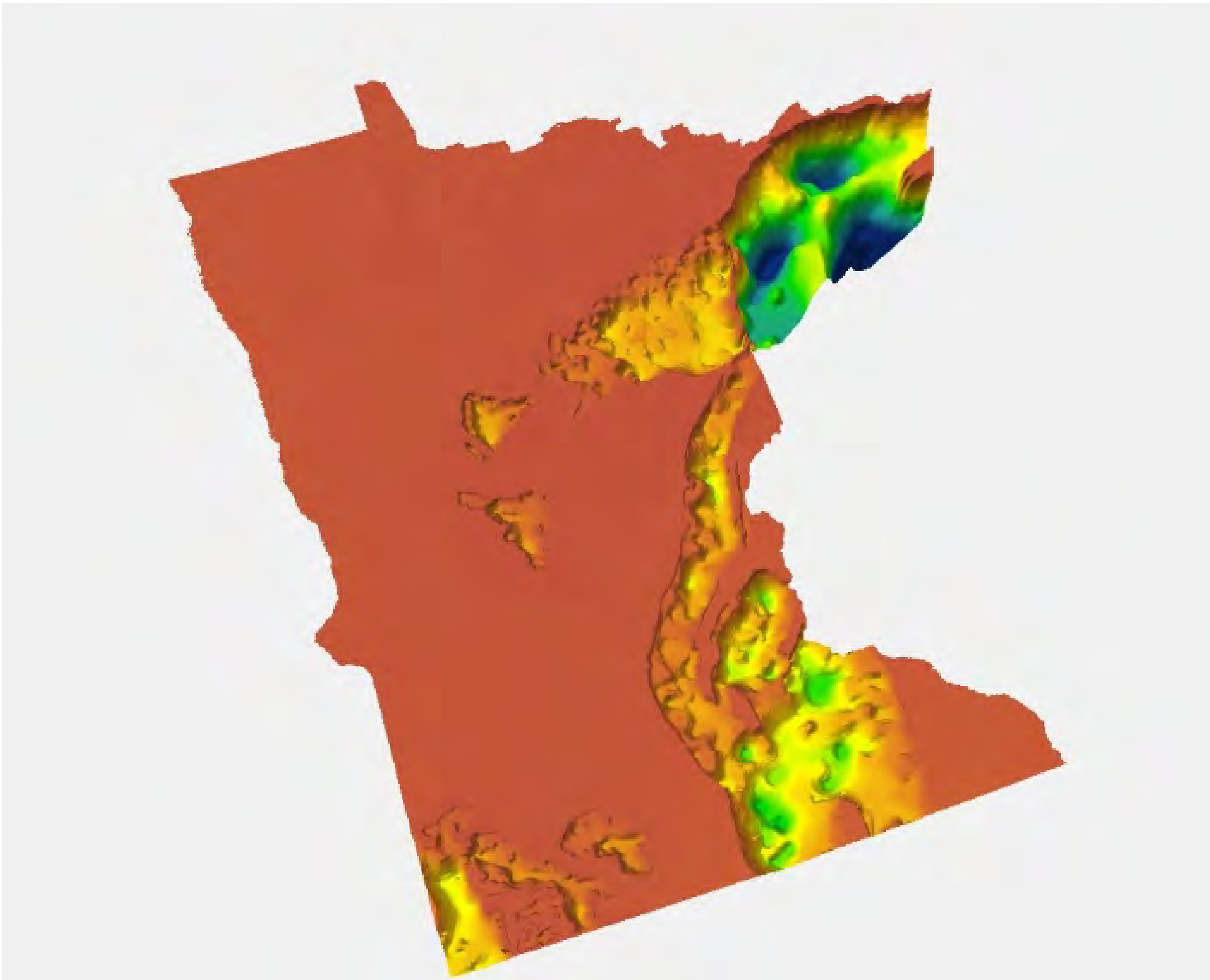


Figure 7.1: Illustration of the new surfaces drawn under Precambrian layers

CHAPTER EIGHT: Layered 1:500,000 statewide bedrock geological mapping database with Mesozoic, Paleozoic, and Precambrian cover rocks as layers above the basement map; supplement to MGS Mapping Database D-05, Bedrock Geology, *M. Jirsa and V.W. Chandler, with Minnesota Geological Survey Staff*

FY19 NGGDPP funding to MGS permitted assembly of layered 1:500,000 statewide bedrock geological mapping, from which Mesozoic, Paleozoic, and Precambrian cover rocks can be removed to reveal a basement map, to optimally support analyses that require the most up-to-date, complete and consistent statewide mapping.

The legend was coded for lithology and age in accordance with USGS practices. Construction of the database required updating of published maps, and significant effort to map geology under Precambrian layers to the extent achievable with available information.

This work was guided by MGS planning that calls for geologic mapping of the state to focus on two levels of resolution for surficial geology, bedrock geology, subsurface geology, bedrock topography, and sediment thickness. The 1:500k level of resolution, derived from published state geologic maps, is being developed concurrent with 1:100k mapping, that is expected to be consistent and complete statewide within a decade.

These plans call for the geological mapping to first be published as authored and peer-reviewed maps, prior to 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. This progressively more seamless mapping is tending to have thickness indicated, while properties, heterogeneity, and uncertainty will gradually be more specified. Parsing of legends facilitates queries that support inference of properties.

The current work represents the first release of an MGS bedrock mapping database that is derived from published state geologic maps and that deviates from the source maps.

The foundation of the 1:500k bedrock databases is the most recent state bedrock map (Jirsa et al., 2011). This map represented a dramatic step forward, based on a new legend, and greatly increased detail, enabled by accumulating fieldwork, detailed mapping, and drillhole data, along with profoundly significant, newly reprocessed, and much-improved statewide magnetic and gravity databases.

Furthermore, the new 1:500k map was for the first time layered, so that Mesozoic strata could be removed to reveal a pre-Mesozoic geology map, and Paleozoic strata could be removed, revealing a Precambrian geology map (Jirsa et al., 2012). This layered approach has also been applied to the Quaternary, so that water, and peat, can be removed from the new 1:500k statewide surficial map (Lusardi et al., 2019).

Removable layering has been extended to the Precambrian as part of the current project. Precambrian 2D map polygons whose thickness was mapped, also as part of this project, include Midcontinent Rift sedimentary basins, the North Shore Volcanic Group/Duluth Complex, Sioux Quartzite, and basins of the Animikie Group that includes the currently-mined areas of iron ore. By mapping geology under these layers, we were able to produce the first basement geologic map of Minnesota (Jirsa et al., *in press*).

Legend tags and text derived from the paper maps, as well as polygon attributes, for this layered database, were developed using MGS practices. During current work, the attributes were also coded for lithology and age in accordance with USGS Minerals and USGS Core Science practices, as indicated by the State Geologic Map Compilation (Horton et al., 2017), and by National Geologic Map Database (NGMDB) draft documentation for the GeMS standard.

The USGS Minerals parsing, generously provided by USGS colleagues, was incorporated into the tables for the GIS files associated with each of the layers and the basement map. This categorization of the 112 units in the

MGS statewide bedrock legend includes categorizations for age range, generalized lithology, as well as more specific lithology with accommodation for multiple lithologic constituents.

The lithologic categorizations include the following terms: alkalic-volcanic, amphibole-schist, andesite, anorthosite, banded-iron-formation, basalt, basaltic-andesite, biotite-schist, carbonate, claystone, conglomerate, conglomerate-sandstone, diorite, dioritic, dolostone, felsic-hypabyssal, felsic-volcanic, gabbro, gabbroic, gneiss, granite, granitic, granodiorite, graywacke, greenstone, hypabyssal, komatiite, lamprophyre, leucocratic-granitic, lignite, limestone, mafic-hypabyssal, mafic-volcanic, marble, marlstone, metabasalt, metaconglomerate, metaintrusive, metavolcanic, mica-schist, migmatite, monzodiorite, monzonite, mudstone, mylonite, norite, orthogneiss, paragneiss, peridotite, plutonic, pyroxenite, quartzite, quartz-monzonite, rhyolite, sandstone, schist, sedimentary, sedimentary-breccia, shale, siltstone, slate, syenite, tonalite, troctolite, and volcanic.

This terminology appears to be compatible with that of the National Geologic Map Database (NGMDB), as indicated by current draft documentation for the GeMS standard.

References

Horton, J. D., San Juan, C. A., and Stoeser, D. B., 2017, The State Geologic Map Compilation (SGMC) geodatabase of the conterminous United States (ver. 1.1, August 2017): U.S. Geological Survey Data Series 1052, 46 p.

Jirsa, M. A., Boerboom, T. J., Chandler, V. W., 2012, Geologic Map of Minnesota, Precambrian Bedrock Geology, Minnesota Geological Survey Map S-22, scale 1:500,000.

Jirsa, M. A., Boerboom, T. J., Chandler, V. W., *in press*, Geologic Map of Minnesota, Basement Geology, Minnesota Geological Survey Map S-24, scale 1:500,000.

Jirsa, M. A., Boerboom, T. J., Chandler, V. W., Mossler, J. H., Runkel, A. C., Setterholm, D. R., 2011, Geologic Map of Minnesota-Bedrock Geology, Minnesota Geological Survey Map S-21, scale 1:500,000.

Lusardi, B. A., Gowan, A. S., McDonald, J. M., Marshall, K. J., Meyer, G. N., and Wagner, K. G., 2019, Geologic Map of Minnesota - Quaternary Geology, Minnesota Geological Survey Map S-23, scale 1:500,000.

Digital files: Supplement to MGS Mapping Database D-05, Bedrock Geology

Packaged in ArcGis Online as a map package. Geodatabase of layered bedrock geology. Map scale 1:500,000. Feature datasets within the geodatabase are divided into Mesozoic, Paleozoic, Precambrian and Basement. Within each division are features with further breakdowns if possible.

Mesozoic: Cretaceous polygons- ka_pg_tbl, kc_pg_tbl, ku_pg_tbl (a=Albion, c=Coleraine, u=undivided);
Jurassic polygons-jurassic_pg_tbl
Paleozoic-paleozoic_pg_tbl
Precambrian- kew_sed_cover_tbl, kew_pg_under_ls_tbl, precambrian_pg_tbl, pc_contacts_faults;
(kew=Keweenawan, ls=Lake Superior)
Basement- basement_pg2_tbl, contacts_faults0716,

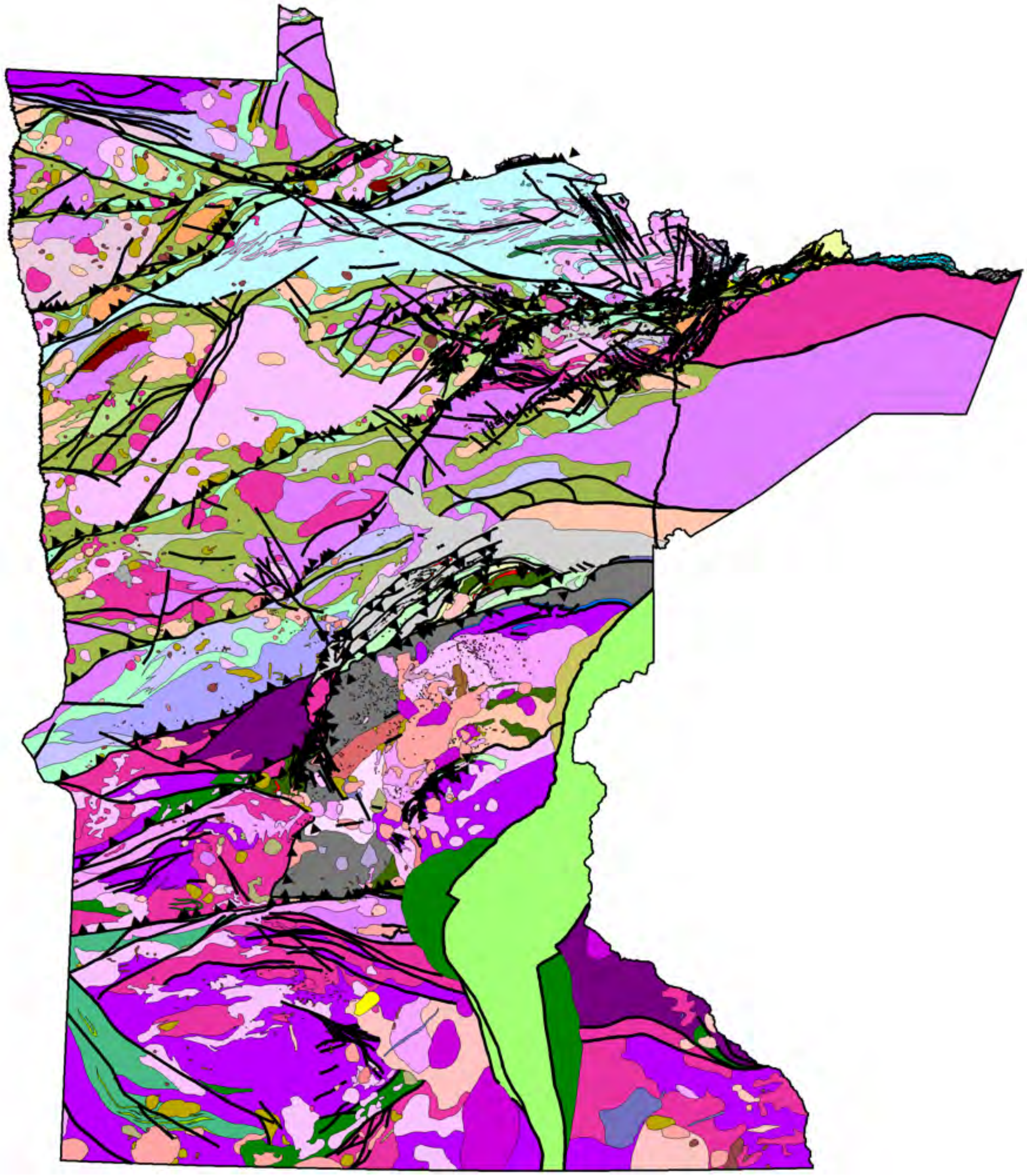


Figure 8.1: Screengrab of the polygons and symbols being developed for the new Basement Geology Map of Minnesota (Jirsa et al., in press)

CHAPTER NINE: Assembled GIS resource without harmonization, with coded legends, for non-superseded 1:100k MGS County Geologic Atlas bedrock geology maps covering about half of Minnesota; supplement to MGS Mapping Database D-05, Bedrock Geology, *M. Jirsa, with Minnesota Geological Survey Staff*

To support GIS analyses that require detailed bedrock geologic mapping in Minnesota, FY19 NGGDPP funding to MGS permitted assembly of available digital GIS files for 1:100k bedrock geology mapping. This synthesis as proposed includes mapping covering about half of the state, as a single, prototype GIS resource without harmonization map-to-map, and with the legends coded in a manner consistent with coding for the 1:500k mapping. In addition, the approach to coding the legends was designed to be similar to completed work for MGS surficial geology maps.

Upon initiation of the work, an approach was chosen that would lead to efficiency in current and anticipated work. On this basis, the compilation of detailed mapping was based only on 1:100k County Geologic Atlas bedrock maps (Setterholm, 2019), that have not been superseded by Atlases updates, and excluding counties - Ramsey and Dakota - for which usable GIS files are not available due to the age of the work.

The 1:100k maps largely are based on field mapping at a scale of 1:24k. Many 1:100k and 1:24k published bedrock geology maps that the Atlas maps were in part based on remain the best reference for work within the extent of those maps.

In contrast, however, the Atlas maps, having incorporated the older, and in some cases slightly more detailed maps, provided a substantial step toward a key objective of the database, which is consistent, statewide mapping needed for successful GIS queries and analyses.

The County Geologic Atlases, however, only cover about half of the state. A small portion of the area not covered by Atlases could have been filled using various published non-Atlas maps. It is anticipated, however, that all of these areas will be infilled by Atlases in coming years, as the Atlas program proceeds to its anticipated statewide completion that has been called for by the Legislature. To avoid repeated effort, it was decided that areas not covered by existing Atlases would be updated with new Atlases in coming years.

In addition, an option for MGS, or for users, is to infill areas not covered by the current synthesis with 1:500k mapping, thus producing a variable-resolution, best-available map.

Setterholm, Dale, R., 2019, Geologic Atlas User's Guide: Using Geologic Maps and Databases for Resource Management and Planning, Minnesota Geological Survey, Open-File Report 12-1, 3rd edition, 29 p.

Digital files: referenced as MGS database d-05, Bedrock Geology. Packaged in ArcGis Online as a map package. Geodatabase labeled county atlas synthesis. Map scale 1:100,000.

Featured data set: Minnesota County Atlas Bedrock Map Synthesis

county_atlas_bedrock_maps with attribute table.

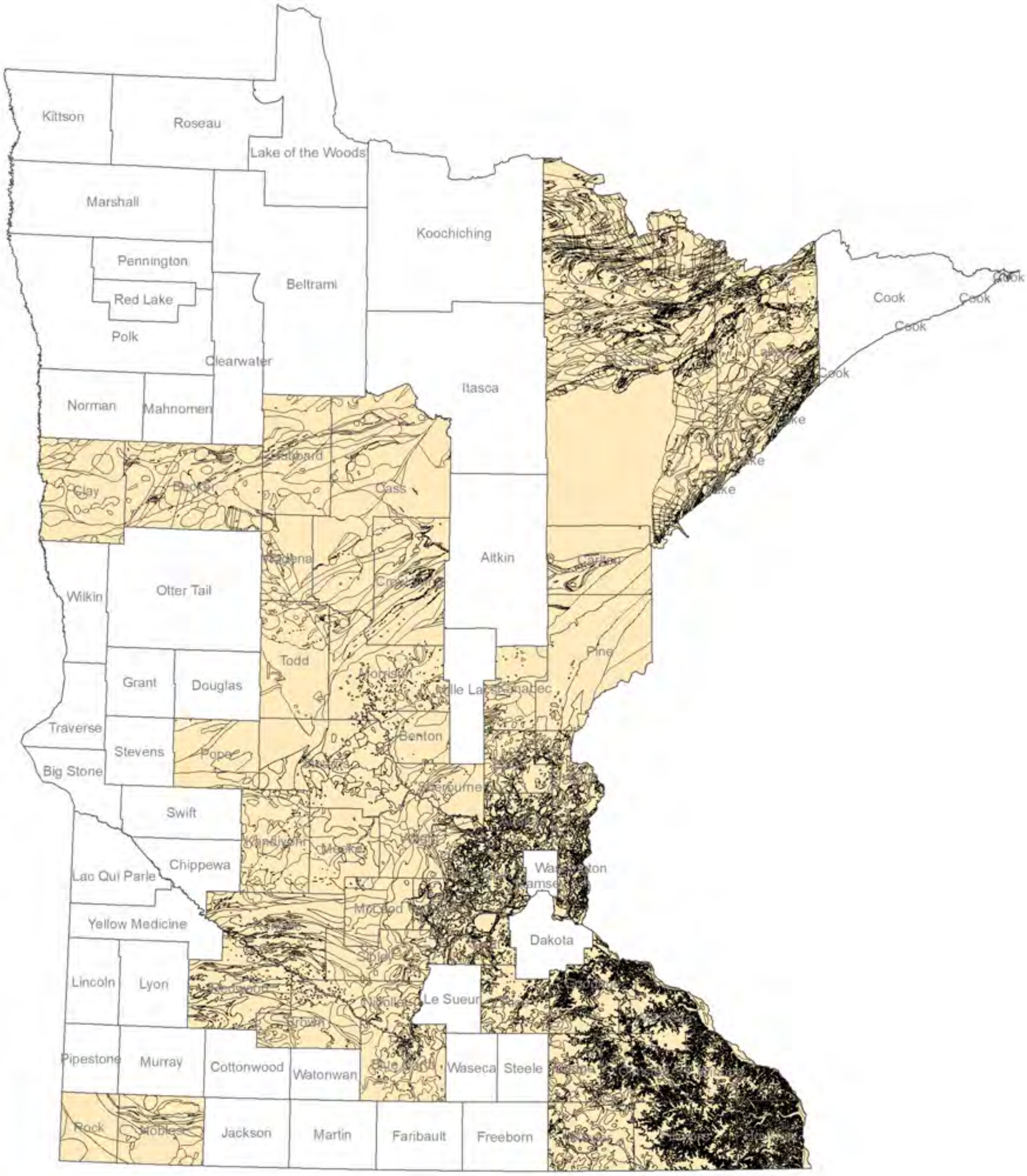


Figure 9.1: Screengrab of the polygons being developed for the new seamless Minnesota County Atlas Bedrock Map Synthesis

CHAPTER TEN: Pilot statewide structure point database derived from Minnesota Geological Survey maps; MGS Mapping Database D-06, Structure database, M. Jirsa, with Minnesota Geological Survey Staff

FY19 NGGDPP funding to MGS permitted development of a pilot statewide structure database derived from MGS maps, to accompany queryable bedrock geology GIS files. The statewide database of structure symbolization was constructed and is maintained by MGS staff. It currently contains over 28,000 GIS points where measurements of planar and linear features were taken from bedrock outcrops. The existing data were compiled from digital map files created by MGS staff since about 2004. The dataset also includes structure measurements transcribed from archived field notes and GIS-rectified analog paper maps that range in vintage from June 2020 (currently) to nearly a century ago. This is not to say that all archival data are necessarily represented, as selections were made based on relevance to the given mapping project and on staff time. The MGS intends to continually update this database with new data as mapping continues and as staff time and project funding allows or requires. The display format of the structure data is ESRI ArcGis representations which creates feature level graphics for each structure type. These display better than older types of structure symbols that relied on ESRI or other fonts and alleviates the problem of the font not drawing when the structure points are exported or displayed as a PDF.

The structure symbology employed here follows the U.S. Geological Survey, Digital Cartographic Standard for Geologic Map Symbolization (USGS Document Number FGDC-STD-013-2006), with slight modifications to accommodate structural features that are specific to MGS data. The following is a modified metadata form that provides pertinent details about the data, with some clarifications for this document.

Dataset name:
Minnesota statewide bedrock structure database (mn_strpt_state.gdb/mn_strpts_state_db)

Author(s):
Minnesota Geological Survey staff

Publishing organization:
Minnesota Geological Survey

Date of publication:
June 2020

Date of data:
1930’s to April, 2020

Key words:
anticline, bedding, cleavage, contact, crenulation, dike, fault, flow, fold, foliation, glacial striation, gneissic, igneous, joint, layering, lineation, metamorphic, slickenlines, syncline, vein

Horizontal accuracy:
Locations of data points based on direct field measurements derived from GPS are accurate to within a few meters. Locations based on data transcribed from analog maps are accurate to 10-30m.

Coordinate system:
UTM, NAD83, zone 15

Area:
State boundary of Minnesota

GIS files associated (ArcGis): mn_strpt_state.gdb

Description of map:
Contains structural measurements acquired by the authors from bedrock outcrops, and those transcribed from published and unpublished analog (non-digital) maps and field notes.

Scale:
Typically acquired at 1:24,000 scale or greater

<u>Attribute Table Structure</u> *(clarifications in italics). Note that some fields appear to be repeated or are blank. This derives from the amalgamation of data sets having somewhat different table structures, methods of reporting orientation, and contain other associated data. The fields are retained in the current dataset to preserve all that authors intended, and to permit future translation of new data sets that may have different attribute table structure.*

OBJECT *sequential numbering*
SHAPE *point*
Orientation *planar vs linear*
Station Identifier *field station number*
Structure Type *Currently a blank "place-holder" to allow importation of new data having different attribute table structures*
Identity Confidence *Currently blank, but allows future assignment of confidence. For example, it may be used to rank variably certain stratigraphic facing directions*
Label *typically simplified structure type*
Plot-At *sets map scale in GIS at which the symbol is visible*
Strike/Trend *in radians 0-360°; Unique strike orientation is established by "right-hand rule" in which strike of the plane is recorded in the direction that produces dip to the right of strike*
Dip/Plunge *0-90°*
Notes *may record geologist name, map name or other pertinent reference*
Data Source *typically more formal reference for data source*
RuleID

FGDC numbers with short descriptions that dictate portrayal of individual field measurements. Each symbol conveys measurement of strike and dip of planar structures, or bearing and plunge (in degrees) of linear ones. Crenulation and fold measurements represent bearing of axial surface trace and plunge.
PLANAR STRUCTURES
6.27 Contact-inclined
6.28 Contact-vertical
2.15.1 Fault-inclined *[fault displacement type and amount, where known, is portrayed by decorations of lines on map]*
2.15.2 Fault-vertical
6.1 Bedding-horizontal
6.2 Bedding-inclined
6.3 Bedding-vertical
6.13 Bedding-inclined upright
6.4 Bedding-inclined overturned
6.14 Bedding-vertical, top *[stratigraphic facing]* indicated
9.2 Stratigraphic facing without bedding *[a linear feature]*
7.2 Cleavage-inclined
7.3 Cleavage-vertical
7.20 Crenulation-inclined
7.21 Crenulation-vertical
8.3.1 Metamorphic foliation-horizontal
8.3.2 Metamorphic foliation-inclined
8.3.3 Metamorphic foliation-vertical

6.33 Approximate foliation via drill core-inclined *[strike estimated from nearby exposures or local geophysical anomaly trends; dip direction is calculated using dip angle of drilling relative to angle of foliation in the core, with some reasonable estimation]*
6.34 Approximate foliation via drill core-vertical
6.35 Approximate foliation via drill core-younging down-hole
6.36 Approximate foliation via drill core-younging up-hole
9.5 Foliation strike-dip unknown
8.3.46 Gneissic layering-horizontal
8.3.47 Gneissic layering-inclined
8.3.48 Gneissic layering-vertical
8.2.10 Igneous textural foliation-horizontal
8.2.11 Igneous textural foliation-inclined
8.2.12 Igneous textural foliation-vertical
8.2.2 Igneous foliation undifferentiated-horizontal *[may be modified in attribute table for specific planar features]*
8.2.3 Igneous foliation undifferentiated-inclined
8.2.4 Igneous foliation undifferentiated-vertical
8.3.14 Shear zone-inclined *[sense of displacement shown by decorations on map]*
8.3.15 Shear zone-vertical
4.3.2 Mafic dike-inclined
4.3.3 Mafic dike-vertical
4.3.8 Felsic dike-inclined
4.3.9 Felsic dike-vertical
4.3.4 Vein-inclined
4.3.6 Vein-vertical
4.3.7 Joint-horizontal
4.3.10 Joint-inclined
4.3.12 Joint-vertical
LINEAR STRUCTURES
5.11.24 Minor syncline-plunge unknown
5.11.4 Minor anticline-plunge unknown
9.109 Lineation of minor antiform/anticline
9.117 Lineation of minor synform/syncline
9.121 Lineation of minor symmetric or M-folds
9.125 Lineation of minor S fold
9.129 Lineation of minor Z fold
9.17 Slickenlines
9.1 Lineation of flow
9.85 Columnar joints
9.25 Lineation of vesicles or amygdules
9.29 Lineation of fragments/clasts
9.37 Lineation of minerals
9.49 Lineation of elongate pillow structures
9.77 Lineation of intersection cleavage/bedding
13.30 Glacial striation-younger
13.32 Glacial striation-older

Override *Refers to rotations in degrees needed for some data sets that used a different recording method from "right-hand rule" that is used here*

SymbolRotation *Records strike direction of planar structure and trend direction of linear ones*

SymbolRotationType *Refers to the rotation "pivot-point" and placement of symbol relative to data point locations; Center Point Rotation centers the symbol over the data point location (typically applied to bedding and other planar foliations); End Point Rotation projects the symbol from data point location (typically applied to lineations, joints, and veins).*

LabelRotation *blank field; place-holder for future imports*
FGDC Reference Number *Number only (no description)*
Gems_code *Largely blank, but it allows importation of symbology from an older MGS system of measurement*
Geologist *Currently blank; likely will be filled with initials of geologists*

List features and accuracy as shown on map, including scales of fieldwork and compilation:
Locations of data based on field measurements are accurate to within a few meters; orientation based on field measurements are accurate to within 5-10 degrees. In areas of abundant iron-formation, a sun compass was employed, and trends of planar and linear features are accurate to 10-15 degrees. Locations of data transcribed from analog maps are accurate within 10-30 m; orientations based on transcription are accurate to about 10 degrees.

Summary of procedures for compiling data used to make map:
Data were compiled from many authors over a period of 40 or more years. Most trends and dips are based on field measurements using Brunton or similar compass. A sun compass was employed in areas of strong magnetic signature, such as iron-formation. Some of the data were taken from historic field notes (locations approximated). Some digital data used a rotation schema different from the one used here. They were converted and verified by visual inspection to conform with the authors' original intent, and with other more recently acquired data in the immediate area. Trends of linear and planar features that were transcribed from GIS-rectified analog maps were visually estimated in GIS. Distinguishing data source, and therefore location accuracy and symbology, is not immediately apparent, but can be inferred in many cases from the reference provided.

Lineage:
This data set was compiled from an assortment of historic analog maps, digital data sets in various formats, and newly acquired data. Specific references to data that was incorporated can be found on published geologic maps of the area of interest.

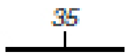
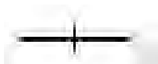
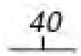
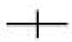
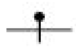
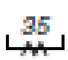
Contact for GIS data:
Richard Lively (lively@umn.edu)

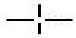
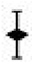
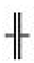
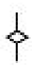
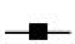
Contact at MGS to obtain map:
Open-Data Portal (https://mngs-umn.opendata.arcgis.com)

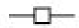
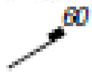
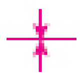
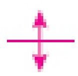
Other comments:

- This set of structural data is compiled from many authors who may refer to various rock fabrics somewhat differently. This is particularly true for metamorphic fabrics that may appear as either metamorphic foliation or cleavage. The former is more generalized; the latter is typically used to distinguish cleavage from bedding in metasedimentary strata to aid interpretation of fold axes and plunges.
- Structure symbols appear in some locations that are not depicted as outcrops on the state outcrop database. These are areas where prior mappers did not portray outcrop, and thus, only structural data were available.
- Regarding glacial striations: note that younger and older striations are distinguished in places where the 2 sets of striations occur and the relative timing can be established. More commonly, only a single set exists, and for these, the younger symbol is used. This is done largely for convenience, but also it might reflect the assumption that evidence of an older event may have been removed by subsequent glacial advances.
- Lineation of flow may be applied to flow features in volcanic rocks, inferred magmatic flow in intrusive rocks, or paleocurrent flow in sedimentary rocks.

Below is a reproduction of structure symbols employed in this dataset

ROTATION point	SYMBOL	FGDC	MGS DESCRIPTION
center		**6.27**	**Contact-inclined**
center		**6.28**	**Contact-vertical**
center		**2.15.1**	**Fault-inclined**
center		**2.15.2**	**Fault-vertical**
center		**6.1**	**Bedding-horizontal**
center		**6.2**	**Bedding-inclined**
center		**6.3**	**Bedding-vertical**
center		**6.13**	**Bedding-inclined upright**
center		**6.4**	**Bedding-inclined overturned**
center		**6.14**	**Bedding-vertical, top indicated**
center		**9.2**	**Stratigraphic facing without bedding**
center		**7.2**	**Cleavage-inclined**
center		**7.3**	**Cleavage-vertical**
center		**7.20**	**Crenulation-inclined**
center		**7.21**	**Crenulation-vertical**
center		**8.3.1**	**Metamorphic foliation-horizontal**
center		**8.3.2**	**Metamorphic foliation-inclined**
center		**8.3.3**	**Metamorphic foliation-vertical**

center		6.33	**Approximate foliation via drill core-inclined**
center		6.34	**Approximate foliation via drill core-vertical**
center		6.35	**Approximate foliation via drill core-younging down-hole**
center		6.36	**Approximate foliation via drill core-younging up-hole**
center		9.5	**Foliation strike-dip unknown**
center		8.3.46	**Gneissic layering-horizontal**
center		8.3.47	**Gneissic layering-inclined**
center		8.3.48	**Gneissic layering-vertical**
center		8.2.10	**Igneous textural foliation-horizontal**
center		8.2.11	**Igneous textural foliation-inclined**
center		8.2.12	**Igneous textural foliation-vertical**
center		8.2.2	**Igneous foliation undifferentiated-horizontal**
center		8.2.3	**Igneous foliation undifferentiated-inclined**
center		8.2.4	**Igneous foliation undifferentiated-vertical**
center		8.3.14	**Shear zone-inclined**
center		8.3.15	**Shear zone-vertical**
center		4.3.2	**Mafic dike-inclined**
center		4.3.3	**Mafic dike-vertical**
center		4.3.8	**Felsic dike-inclined**

center		4.3.9	**Felsic dike-vertical**
end		4.3.4	**Vein-inclined**
end		4.3.6	**Vein-vertical**
end		4.3.7	**Joint-horizontal**
end		4.3.10	**Joint-inclined**
end		4.3.12	**Joint-vertical**
center		5.11.24	**Minor syncline-plunge unknown**
center		5.11.4	**Minor anticline-plunge unknown**
center		9.109	**Lineation of minor antiform/anticline**
center		9.117	**Lineation of minor synform/syncline**
center		9.121	**Lineation of minor symmetric or M-folds**
center		9.125	**Lineation of minor S fold**
center		9.129	**Lineation of minor Z fold**
end		9.17	**Slickenlines**
center		9.1	**Lineation of flow**
center		9.85	**Columnar joints**
end		9.25	**Lineation of vesicles or amygdules**
end		9.29	**Lineation of fragments/clasts**
end		9.37	**Lineation of minerals**

end		**9.49**	**Lineation of elongate pillow structures**
end		**9.77**	**Lineation of intersection cleavage/bedding**
center		**13.30**	**Glacial striations-younger**
center		**13.32**	**Glacial striations-older**

referenced as MGS database d-06, Structure Database. Packaged in ArcGis Online as a map package.

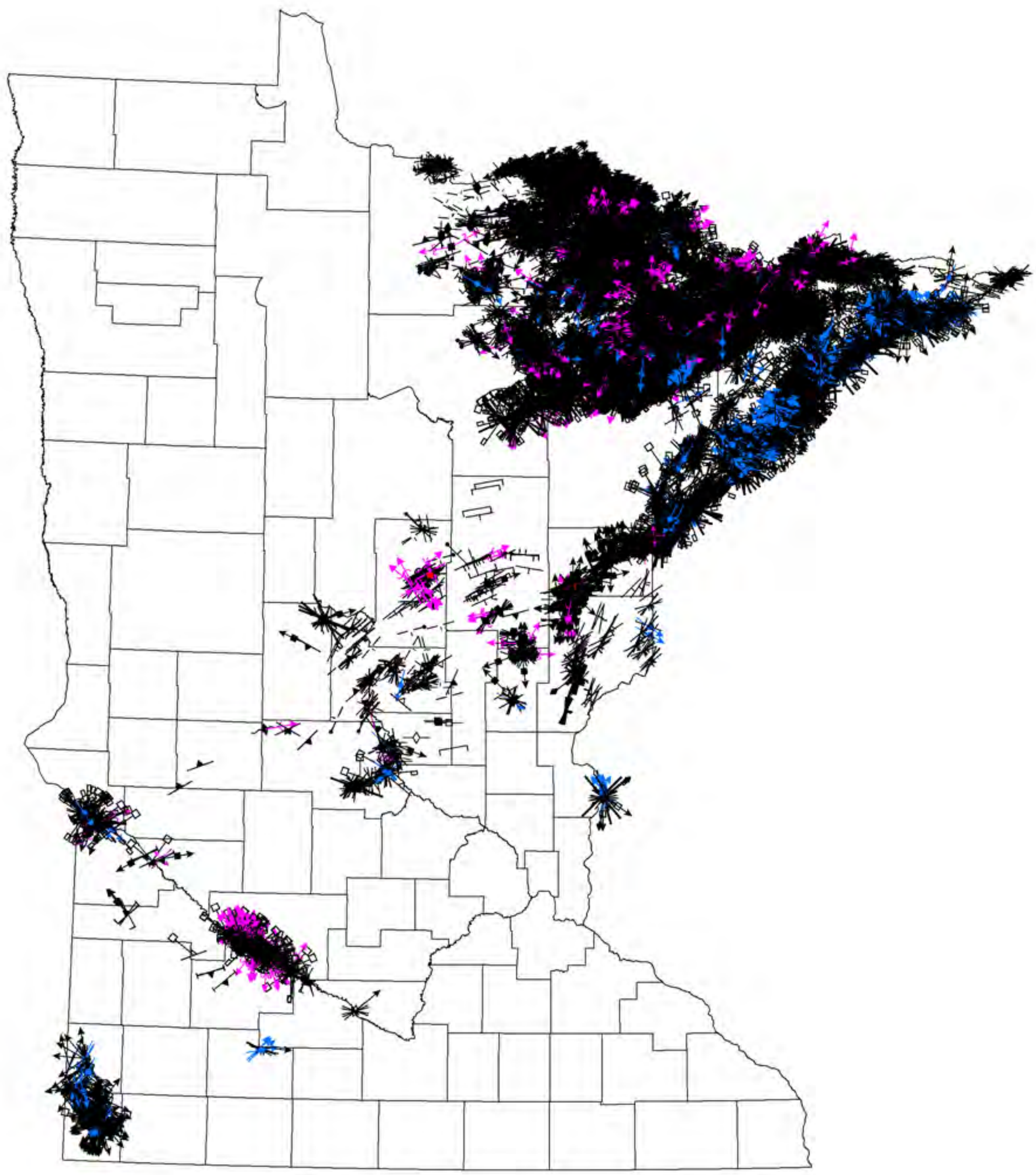


Figure 10.1: Screengrab of symbols in the pilot Minnesota statewide bedrock structure database

CHAPTER ELEVEN: Pilot statewide outcrop database based on Minnesota Geological Survey mapping; MGS Mapping Database D-02, Outcrop database, *Minnesota Geological Survey Staff*

FY19 NGGDPP funding to MGS permitted development of a pilot statewide bedrock outcrop database based on MGS mapping, to accompany queryable bedrock geology GIS files. The outcrop database for Minnesota (Figure 10.1) is a statewide dataset, although there are many parts of the state where no outcrops occur due to thick glacial cover. In addition, many more outcrops are likely to be found, and these will be added to the database as mapping progresses.

Outcrop locations in Minnesota have been collected since the early days of mapping in the state in the late 1800's, and continuing through the present. The pilot outcrop database presented here is an effort to bring together outcrops that have been digitized from paper maps, with those collected with GPS locations and polygons generated in GIS using topography and LiDAR maps as the background. The current database, which contains over 205,000 outcrop polygons, is functioning well as a repository for both old and new data.

Outcrop polygons were digitized by MGS staff in the course of mapping projects, digitally transcribed from analog paper maps that were scanned and rectified, and acquired from digital datasets of other organizations, individuals, and companies. Misplacement of some attributes and other inconsistencies are the result of the compilation of diverse datasets, each with somewhat different attribute table structure. Correction and full attribution is an ongoing process. The mapping has accuracy varying from a few feet to as much as hundreds of feet, depending on original detail of the published map from which the outcrops were transcribed, the basemap accuracy, and the extent to which outcrops were field verified. Transcription from older publications that used less detailed base maps typically will have lower accuracy. Those acquired using air photos, lidar, and field visits are most accurate. In many cases outcrop polygons enclose multiple small bedrock exposures. In some areas, outcrop is represented by partially overlapping, but differently shaped polygons. These represent areas where data were acquired from 2 or more authors. In many cases, overlapping polygons are being retained, to keep a record of interpretations over time.

The reliability thus is variable, at scales ranging from 1:12,000 to 1:100,000. Outcrops, which were drawn from a combination of lidar, air photo, and fieldwork, may be viewed at scales as detailed as 1:5000.

Attributes include but are not limited to Field station, rock type, rock name1, 2, 3, description and geologist 1, 2, and a source reference. Not all of the attributes are filled out or even capable of being completely filled out. In many cases, the database can only provide a location and general polygon shape.

Dataset name: MGS_Outcrop2020.

Minnesota statewide bedrock outcrop database

MGS Mapping Database D-02, Outcrop database. Packaged in ArcGis Online as a map package.

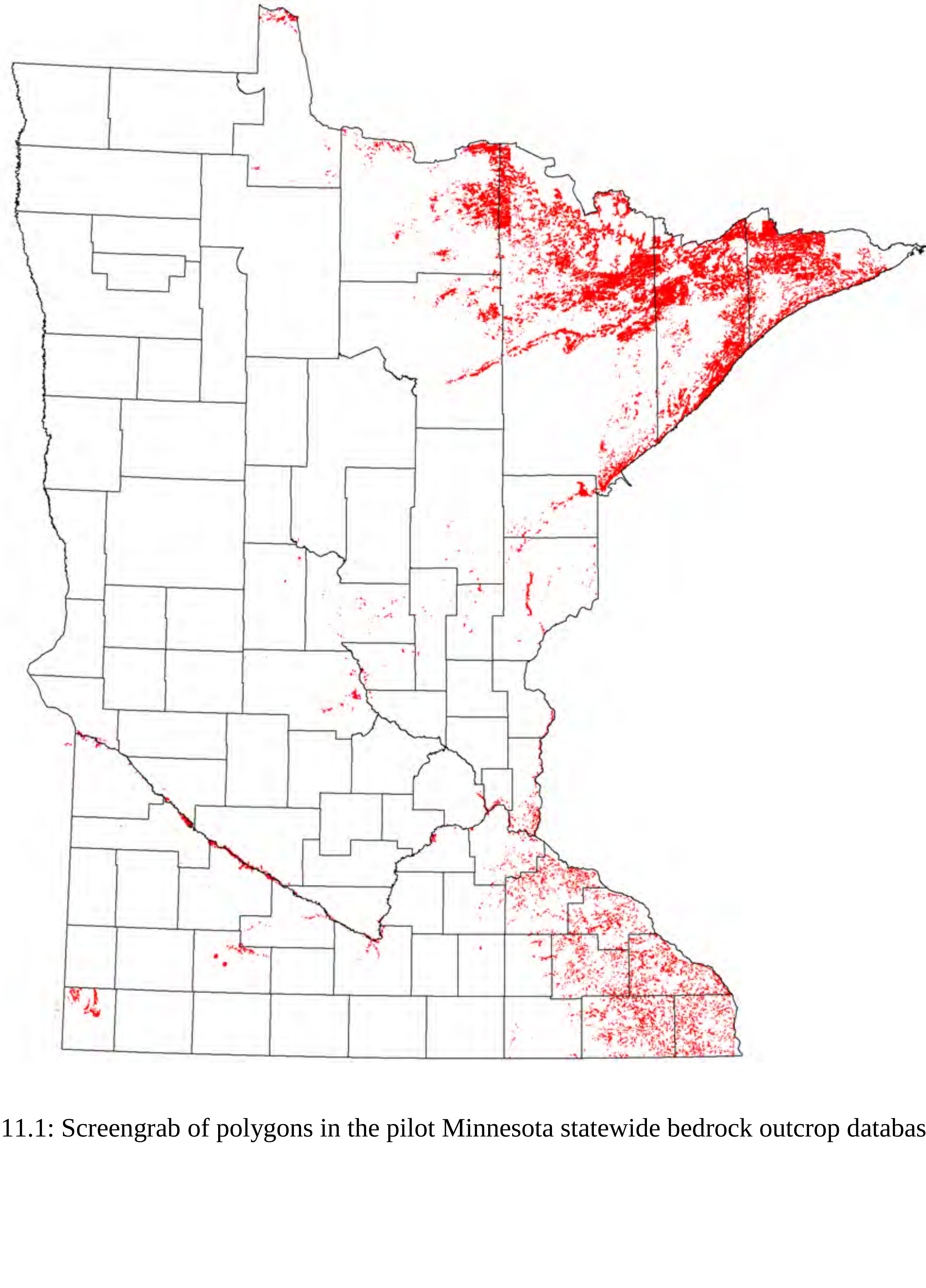


Figure 11.1: Screengrab of polygons in the pilot Minnesota statewide bedrock outcrop database

CHAPTER TWELVE: Statewide Precambrian geochronological database; MGS Mapping Database D-07, Precambrian geochronology database, *T. Boerboom, Minnesota Geological Survey (MGS)*

The Precambrian geochronological database for Minnesota was constructed as a means for users to easily locate and utilize the available Precambrian geochronological analyses available in the state. A few analyses from neighboring states are included. The database was compiled from all available scientific publications and the locations were taken from those publications, or where the location was not clear, by contacting the authors of the papers. In addition, the database includes many new analyses obtained by MGS which have not yet been widely published, and this provides a means to make those dates known and available to the public. The database only includes analyses that utilize modern and more precise dating methods, as well as a few older analyses that are judged to be of sound scientific value.

The database includes location, sample number, age, an interpretation of the age, the method, the geologic implications, notes about the sample, the geologic unit, and the reference source. It is viewable on a webmap hosted by MGS, and it can be downloaded in a variety of formats including a spreadsheet, KML, shapefile, and geodatabase. The metadata is located with the file.

MGS staff will update the database on a regular basis as new analyses are obtained or published. Currently there are 303 data points listed in the database. Attributes include Sample, Age, Interpretation, Method, System, Provenance and/or Terrane, Notes, Unit, Reference, County, Age (MY), Error (MY), Status, Full Reference, Latitude, Longitude.

Dataset name: MGS Mapping Database D-07, Precambrian geochronology database. Packaged in ArcGis Online as a map package

Minnesota statewide Precambrian geochronological database File: Precambrian bedrock dates nonproprietary latlong. Data from nonproprietary sources with latitude and longitude in the attribute table.

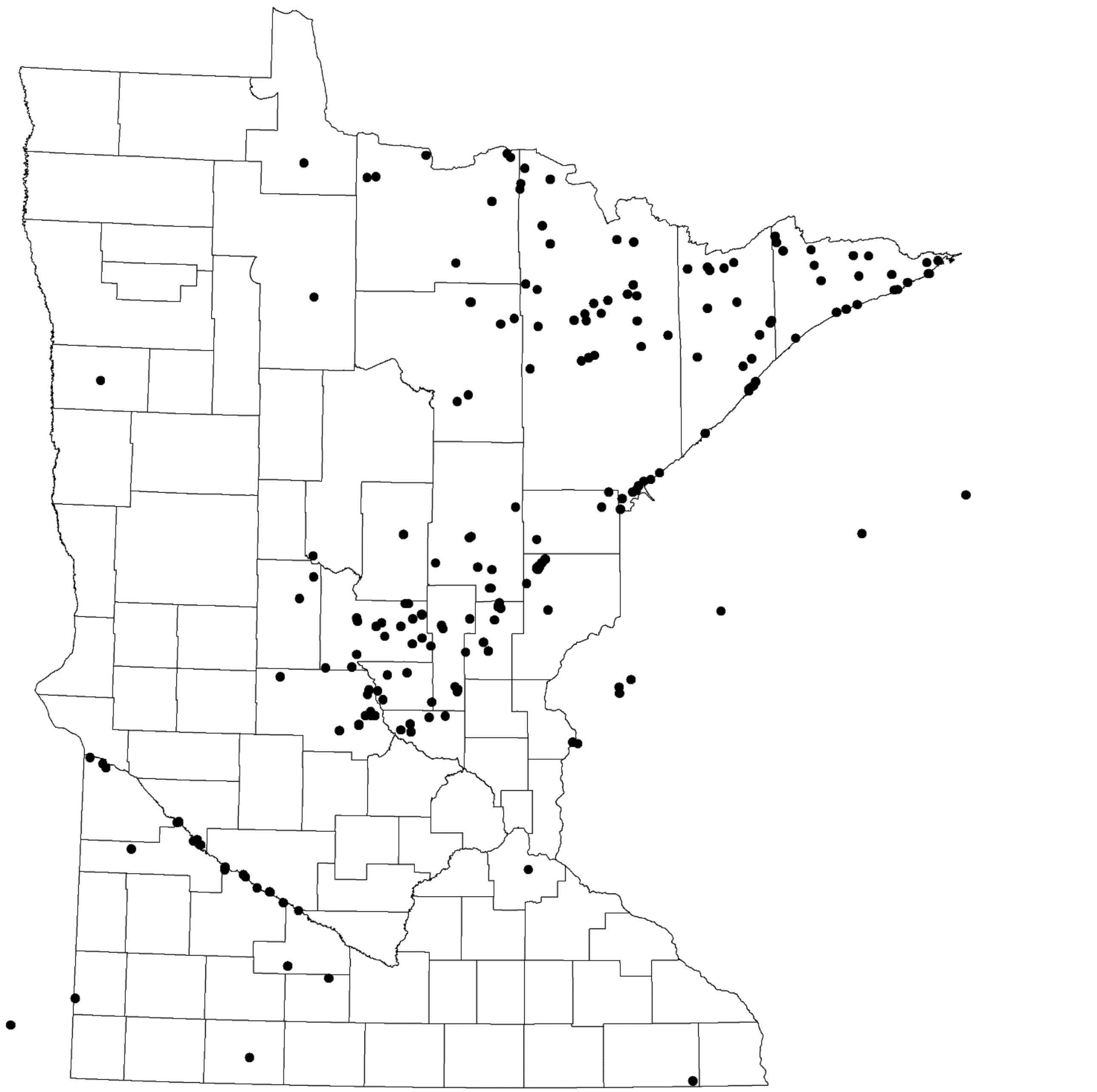


Figure 12.1: Location of points in the pilot Minnesota statewide Precambrian geochronological database

Appendix A: Minnesota Earth MRI Confluence Documents and Data
Uploaded to USGS Confluence web site 12-14-2019

Documents uploaded to directory USGS → Confluence → Earth MRI → States → Central → Minnesota

4 page focus area write ups

1) FY19-EarthMRI-Focus Southern Duluth Complex Priority Area-4page_Final1.docx
2) FY19-EarthMRI-Focus Mentor Priority Area_4page_Final1.docx

Attachment E Spreadsheet of Critical Mineral Phase II Deposits

3) Mineral Deposit Info Minnesota.xlsx (corrected version uploaded 3-6-2020)

GIS boundaries for focus area write ups

4) SouthernDuluthComplexOutline.zip
5) MentorAreaOutline.zip

Southern Duluth Complex Focus Area Supporting Data and GIS Files

6) MGS-RI-58-DuluthComplex-Report.pdf
7) MGS-RI-58-DuluthComplex-Data-Plates.zip
8) GraphiteOccurrenceAtCloquetValleyNorthGrid.pdf

Mentor Focus Area Supporting Data and GIS Files

9) MGS-OFR-2006-03-PGE-Project-Summary.pdf
10) MGS-OFR-2006-03-PGE-GIS.zip
11) MGS-OFR-2006-03-PGE-ReadMe.pdf

GIS Areas of Nonferrous Metals Active Exploration and Cumulative Exploration on State Lands (as of December 3, 2019)

12) StateOfMinnesotaActiveNonferrousLeases.zip
13) StateOfMinnesotaNonferrousLeasingCumulative.zip

Note: GIS files using UTM coordinates are cast in UTM Zone 15 with x and y ordinates in meters, NAD83 Datum

APPENDIX B: SUMMARY OF ACCOMPANYING DATABASES**:**

1. Minnesota Winchell rock catalog
2. Minnesota Pillsbury Hall rock catalog
3. Minnesota nonferrous mineral deposits
4. Minnesota public drill core
5. Minnesota nonferrous leasing
6. Minnesota research on mineral potential
7. Minnesota depth to bedrock database
8. Minnesota depth to pre-Mesozoic database
9. Minnesota depth to Precambrian database
10. Minnesota depth to basement database
11. Minnesota 1:500k geological mapping database
12. Minnesota 1:100k County Atlas bedrock map database
13. Minnesota statewide bedrock structure database
14. Minnesota statewide bedrock outcrop database
15. Minnesota statewide Precambrian geochronological database