UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
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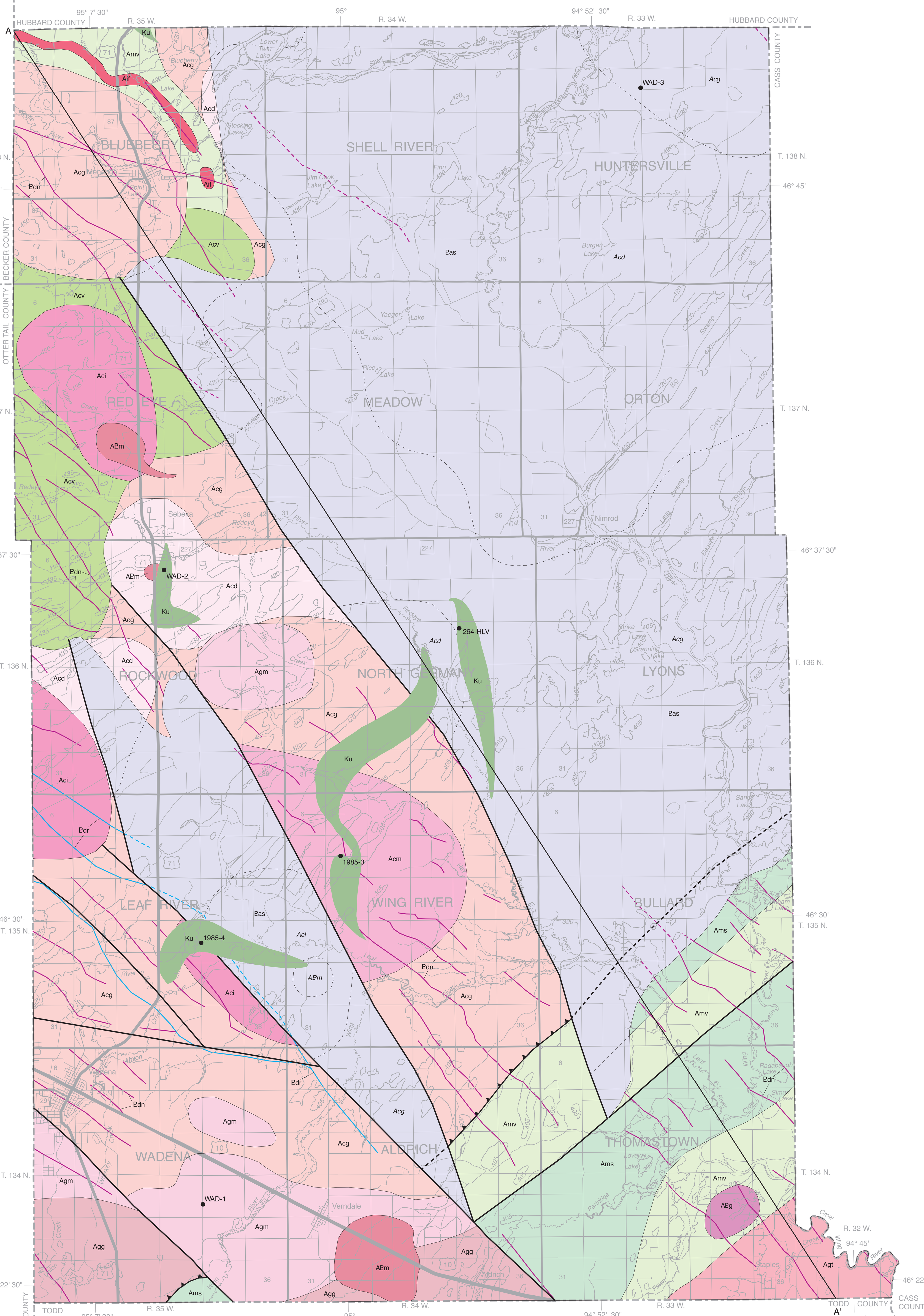
COUNTY ATLAS SERIES
ATLAS C-40, PART A
Wadena County
Plate 2—Bedrock Geology

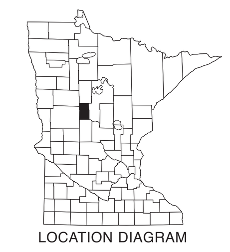
BEDROCK GEOLOGY

By

Amy L. Radakovich and V.W. Chandler

2016





Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by the Minnesota Geological Survey.

Elevation contours were derived from the U.S. Geological Survey 30-meter Digital Elevation Model (DEM) by the Minnesota Geological Survey.

Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

SCALE 1:100 000

CONTOUR INTERVAL 15 METERS

MAP SYMBOLS

Geologic contact—Contacts in Archean and Paleoproterozoic rocks are inferred exclusively from geophysical maps and models, locally anchored by drill-hole data. Geophysical modeling indicates that most contacts are nearly vertical. Dashed where concealed by rocks of the Animikie Group (unit Ᵽas). Cretaceous strata are shallowly dipping and based on limited drill-hole data, thus no contact line is used at the unit boundaries.

Fault—Inferred from geophysical data; typically steeply dipping. Both strike-slip and dip-slip senses of fault motion are likely; however, the precise offset sense and amount are unknown.

Vining Geophysical Lineament—Regionally extensive, steeply northward dipping fault zone. Location is inferred from geophysical maps and models. Interpreted to be a thrust fault feature related to the northward-directed tectonic assembly of the Archean Superior Province as evidenced by outcrop and drilling data in areas of Minnesota where the geology is better constrained. Dashed where concealed beneath Paleoproterozoic rocks.

Cored bedrock drill hole—Location of a drill hole for which core or cuttings samples are available.

Line of geophysical modeling profile—Shown on Figure 3.

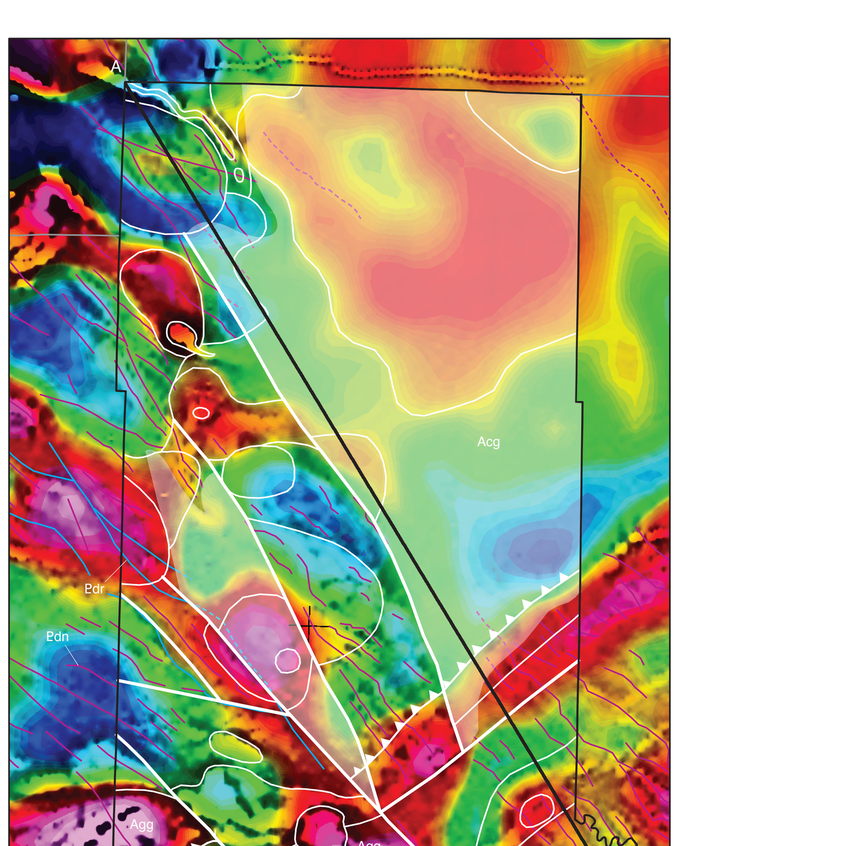


Figure 2. Geophysical map of the Wadena County area. The map shows superimposed geophysical images of first vertical derivative magnetic anomaly data (gray scale) and second vertical derivative gravity data (color), commonly referred to as a Superimposed Magnetic On Gravity (SMOG) image. First vertical derivative magnetic values range from approximately -200 (black) to 200 (white) nanoTeslas/km, and second vertical derivative gravity values range from approximately -0.25 (blue) to 0.25 (magenta) milligals/km^2. Both sets of data are reduced to vertical polarization. White lines represent geologic contacts (narrow) and faults (thicker, or with teeth). Cretaceous units (unit Ku) are not included on the map because they are essentially transparent to the geophysical methods employed here. Narrow northwest-trending purple (unit Ᵽdn) and blue (unit Ᵽdr) lines represent the trajectories of normally and reversely polarized diabase dikes, respectively, based on magnetic lineaments. These dike trajectories are dashed where dikes are concealed beneath Animikie Group sediments. The black line labeled A–A' represents the location of the geophysical model profile and cross section in Figure 3. Areas with translucent white shading represent locations of Paleoproterozoic sedimentary strata (unit Ᵽas) that cover the Archean bedrock contacts displayed below. In areas of no outcrop and scant drill-hole data like Wadena County, much of the geologic map was constructed by inferring bedrock characteristics from geophysical signatures shown on this map. For example, low-density, non-magnetic rocks, such as the granitic rocks of the Cass batholith (unit Acg), typically exhibit low second vertical derivative gravity values (shades of blue, green, and yellow) and a subdued first vertical derivative magnetic signature (darker shades). Conversely, very dense and strongly magnetic rocks, such as the gabbroic to dioritic intrusions of unit Agg, exhibit pronounced highs in both second vertical derivative gravity data (red and pink) and first vertical derivative magnetic data (light/bright white shades). Such relationships between geophysical characteristics and rock type are the basis for geologic mapping of Precambrian bedrock in poorly exposed areas.

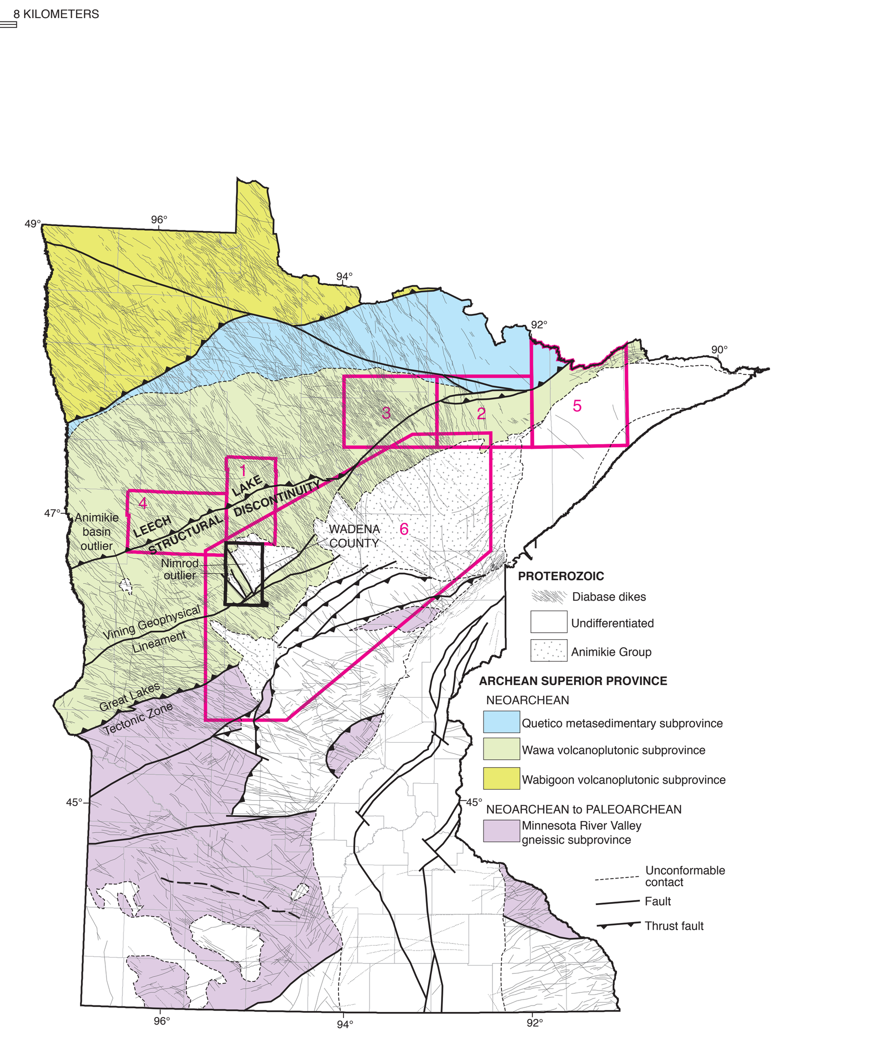


Figure 1. Generalized bedrock terrane map of Minnesota, showing the location of subprovinces of the Archean Superior Province in color and major bounding faults and unconformities (modified from Jirsa and others, 2011). Wadena County is outlined in black. Magenta outlines show published maps referenced in the Introduction and are labeled using numbers that relate to those in the References. Areas with a stippled pattern show the extent of the main Animikie basin and the Nimrod outlier.

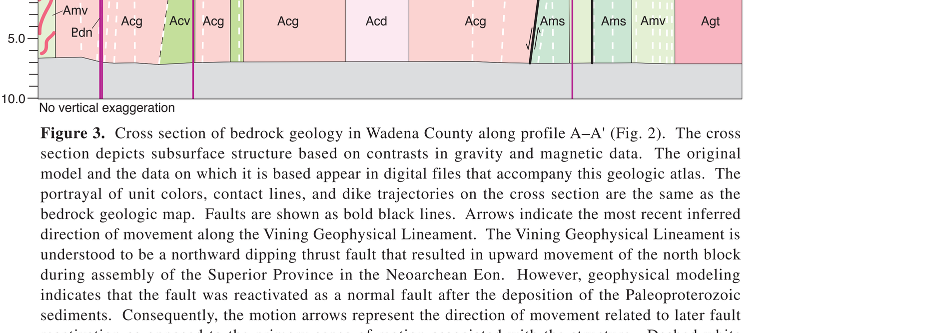
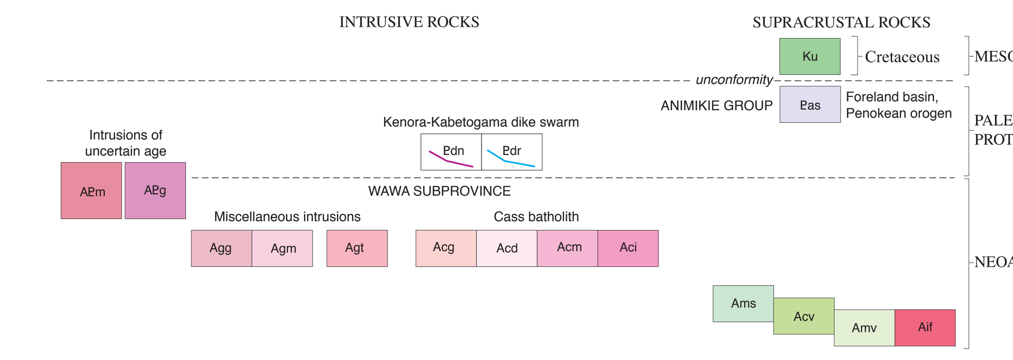


Figure 3. Cross section of bedrock geology in Wadena County along profile A–A' (Fig. 2). The cross section depicts subsurface structure based on contrasts in gravity and magnetic data. The original model and the data on which it is based appear in digital files that accompany this geologic atlas. The portrayal of unit colors, contact lines, and dike trajectories on the cross section are the same as the bedrock geologic map. Faults are shown as bold black lines. Arrows indicate the most recent inferred direction of movement along the Vining Geophysical Lineament. The Vining Geophysical Lineament is understood to be a northward dipping thrust fault that resulted in upward movement of the north block during assembly of the Superior Province in the Neoarchean Eon. However, geophysical modeling indicates that the fault was reactivated as a normal fault after the deposition of the Paleoproterozoic sediments. Consequently, the motion arrows represent the direction of movement related to later fault reactivation as opposed to the primary sense of motion associated with the structure. Dashed white lines are model-based boundaries between bodies that show minor geophysical contrast within a map unit. These probably represent slight variations in rock composition, and may be an indication of the trend of layering or other foliation within the rock. No vertical exaggeration is shown, which renders the land surface nearly horizontal at this scale (1:400,000).

CORRELATION OF MAP UNITS



INTRODUCTION

Wadena County bedrock consists of a complex assemblage of Precambrian supracrustal and intrusive rocks, locally overlain by varying thicknesses of weathering residuum (saprolite) and Cretaceous sedimentary strata. Quaternary glacial sediment covers the bedrock across the entire county (Plate 3, *Surficial Geology*). The bedrock map depicts the type of bedrock likely to be encountered below the unconsolidated sediment.

There are no known exposures of bedrock at the surface in Wadena County, thus the interpretation of the bedrock geology relied almost entirely on geophysical data augmented by sparse drilling data (Plate 1, *Data-Base Map*). One hole was drilled in 1986 for the purpose of minerals exploration, but because no bedrock drill core or cuttings from this hole were preserved, the geologic interpretation relied on the original written logs. Two other drill cores (1985-3 and 1985-4) obtained as part of a scientific study by the Minnesota Geological Survey, stored at the Minnesota Department of Natural Resources—Hibbing office, were re-examined as part of this study. Additional bedrock information came from bedrock and saprolite core intersected in two of three rotary-sonic holes drilled by the Minnesota Geologic Survey for this atlas. In addition to exploration and scientific drill-hole data, driller's logs from both municipal and private well drilling were used to characterize the depth to and nature of the bedrock. In areas lacking any subsurface drilling information, the bedrock geology was mapped using geophysical data, specifically gravity and magnetic data (Fig. 2). Geophysical interpretations were based on comparisons with areas to the east where the bedrock is better understood through surface exposures and more complete drilling data (Fig. 1; Southwick and others, 1988; Jirsa and Boerboom, 2003; Jirsa and Miller, 2004; Jirsa and Chandler, 2007). In addition, active seismic data collected by the Minnesota Department of Natural Resources, and Horizontal to Vertical Spectral Ratio (HVSR) passive seismic data collected by the Minnesota Geologic Survey, were used to refine depth to bedrock (Plate 1).

Prior to this mapping, the most recent depictions of the bedrock geology for all or parts of Wadena County were a 1:250,000 regional map by Southwick and others (1988; Fig. 1) and a 1:500,000 statewide bedrock geologic map (Jirsa and others, 2011). A bedrock map of neighboring Todd County was completed in 2007 (Boerboom, 2007), and bedrock geology maps for adjacent Becker (Jirsa and Chandler, 2016) and Hubbard (Chandler and Radakovich, in press) Counties (Fig. 1) are in progress. This map reflects moderate revisions from the statewide bedrock geologic map (Jirsa and others, 2011), and largely correlates with mapping underway in adjacent counties (Jirsa and Chandler, 2016; Chandler and Radakovich, in press).

GEOLOGIC HISTORY

Archean

Archean intrusive and supracrustal rocks of approximately 2.7 Ga (billion years old) form the basement bedrock across all of Wadena County. In the northeastern and central parts of the county, these Archean rocks are overlain by younger sedimentary rocks from the Paleoproterozoic Era (approximately 1.9 to 1.8 Ga). Additional sedimentary strata from the Cretaceous Period (100 to 89.8 Ma) overlie both Archean and Proterozoic bedrock in localized areas across the county. Drill-hole data are sparse and no outcrops exist due to thick glacial sediment cover. As a result, an interpretation of the complex geologic history of these rocks relies heavily on comparison of bedrock geophysical characteristics (Fig. 2) with those in areas of greater outcrop and drill-hole data density (Jirsa and Boerboom, 2003; Jirsa and Miller, 2004; Jirsa and Chandler, 2007).

The Archean bedrock of Wadena County is part of the Neoarchean (2.8 to 2.5 Ga) Superior Province. The Superior Province is a vast, stable continental craton extending from northern Ontario southward through southern Minnesota, which was assembled during the Neoarchean Eon. The province is composed of numerous subprovinces (such as the Wabigoon, Quetico, Wawa, and Minnesota River Valley subprovinces; Fig. 1) of three general types: 1. Volcano-sedimentary sequences intruded by granitic rocks (known as greenstone-granite belts), 2. Thick sequences of variably metamorphosed metasedimentary rocks, and 3. Gneissic to plutonic proto-continents amalgamated to the other terranes (Fig. 1). These subprovinces can be tens to hundreds of kilometers wide and hundreds to over 1,000 kilometers long and have become juxtaposed in a complex tectonic history spanning the late Archean Eon. The Archean rocks of Wadena County are part of a greenstone-granite terrane known as the Wawa subprovince (Fig. 1) that is characterized by east–northeast trending elongated "belts" of mafic volcanic and hypabyssal intrusive rocks (the "greenstone" component), which were intruded by granitic plutonic material (the "granite" component) and other intrusive components ranging from ultramafic to intermediate in composition. In Wadena County the mafic greenstone belts (units Amv, Acv) likely include calc-alkalic basalts and minor mafic intrusions such as gabbros, as well as volcaniclastic sedimentary rocks (unit Ams). These mafic volcanic belts also host steeply dipping layers of strongly magnetic iron formation interbedded with volcanic rocks (unit Aif). The iron formation is readily identifiable on aeromagnetic maps, and has been positively identified by drilling in neighboring counties. Archean felsic to intermediate intrusive rocks (units Acg, Acd, Acm, Aci) of the Cass batholith within the larger Wawa subprovince are locally identified in drill core and have been mapped based on their distinctive ovoid shapes and aeromagnetic signatures (units Agm, Agg, Agt).

As major geologic terranes came together in the Archean Eon, large fault zones such as the Vining Geophysical Lineament (Figs. 1, 3) in Wadena County developed between them. The Vining Geophysical Lineament was once likely a low-angle thrust fault that accommodated suturing of several terranes to the growing Superior Province. However, geophysical modeling (Fig. 3) indicates that the Vining Geophysical Lineament now dips very steeply northward, likely a consequence of extensive tectonic activity that continued for many millions of years as the Superior Province continued to grow. This tectonic activity severely deformed the rocks all along the southern margin of the Superior Province, particularly the near-surface supracrustal rocks, and consequently many of the Archean rocks of Wadena County have been metamorphosed to upper greenschist and possibly even lower amphibolite facies.

Paleoproterozoic or Neoarchean

Intrusions of uncertain age

Some intrusive rocks (units AⱣm, AⱣg), identified only by geophysical signature, cannot be definitively classified as either late Archean or very early Paleoproterozoic rocks. These intrusions, therefore, are classified as being of uncertain age, though most likely they are late Archean in age.

Paleoproterozoic

Paleoproterozoic rocks overlie (unit Ᵽas), and locally intrude (units Ᵽdn, Ᵽdr), Archean bedrock throughout Wadena County.

Kenora-Kabetogama dike swarm

Subsequent to the development of the Archean granite-greenstone terrane, a regionally extensive suite of diabase dikes called the Kenora-Kabetogama dike swarm was emplaced into the Archean bedrock. The majority of these dikes have a distinct northwest trend (approximately 330° in Wadena County) and are traceable by their positive linear aeromagnetic signature (unit Ᵽdn). A smaller number of reversely polarized dikes (unit Ᵽdr) exhibiting negative aeromagnetic signatures and trending approximately 300° to 330° appear to be part of the Kenora-Kabetogama dike swarm, though their age relationship with the normally polarized dikes is unclear. In northern Minnesota, dikes of the Kenora-Kabetogama swarm range in width from 3 to 394 feet (1 to 120 meters), and are traceable for as far as 75 miles (120 kilometers; Southwick and Day, 1983; Southwick and Halls, 1987). A mid-Paleoproterozoic age of approximately 2,070 Ma is inferred for these rocks based on age dates obtained from other diabase dikes of this swarm across Minnesota and Ontario (Buchan and others, 1996; Schmitz and others, 2006; Chamberlain, unpub. data). This age is consistent with the presence of the dikes within the Archean basement of Wadena County and their absence from younger rocks of the Animikie Group.

The Animikie Group

Between 1.9 and 1.7 Ga, a craton-wide mountain-building event called the Penokean Orogen occurred along the southern edge of the Archean Superior Province approximately 31 miles (50 kilometers) south and east of Wadena County. Though the orogenic belt is located southeast of Wadena County, crustal thickening during the Penokean Orogen caused the lithosphere to bend, creating a foreland basin north of the orogen. Large volumes of sediment eroded from the thickened and uplifted crust to the south and the older Archean basement to the north filled this foreland basin with a sedimentary succession known as the Animikie Group. The Animikie Group is a shallowly-dipping, generally undeformed sedimentary sequence in which regionally extensive basal quartzite and iron formation are overlain by a thick argillite to graywacke sequence known as the Virginia Formation. The entire stratigraphic sequence is present in the main Animikie basin, which covers much of Cass, Itasca, Crow Wing, St. Louis, and Carlton Counties (Fig. 1; Jirsa and others, 2011). However, the Nimrod outlier in Wadena County (Figs. 1, 3) is considered to be an erosional remnant of the larger basin in which the Animikie Group was deposited. Only the upper argillite sequence (unit Ᵽas) has been identified in the Nimrod outlier, possibly consistent with its location at a more distal part of the original Animikie basin. Based on the abrupt change in thickness of the Nimrod outlier across the Vining Geophysical Lineament (Fig. 3), it appears that the Vining Geophysical Lineament was reactivated as a normal fault at some time during or after the deposition of the Animikie Group.

Precambrian saprolite horizon

The Precambrian rocks of north-central Minnesota underwent extensive chemical weathering between the time of their exhumation and the late Cretaceous Period, when the overlying strata were deposited. This created a weathering horizon that at present varies from less than 3 feet (1 meter) to 50 feet (15 meters) or more in thickness in the Precambrian units throughout Wadena County, as indicated from scant drill-hole records. Weathering profiles vary among different rock types, but typically progress downward from a horizon of saprolite (extremely weathered bedrock) at the bedrock surface, to less weathered and more competent saprock that transitions downward to fresh rock. Saprolite is commonly white to blue/green clay, which is produced by nearly complete chemical weathering of feldspar components in the bedrock. Saprock is also heavily weathered but not so severely as to completely obscure original mineralogy and/or texture of the parent rock. This saprolite horizon was likely widespread throughout north-central Minnesota, though it has been removed in some places as a result of subsequent erosion, mainly by glaciation, in the past 2 million years.

Cretaceous

Between approximately 99 and 89.8 Ma, in the Cenomanian and Turonian ages of the late Cretaceous Period, sediments were deposited unconformably on top of Precambrian bedrock and the saprolite horizon over an extensive area of western and central Minnesota. These upper Cretaceous sediments were deposited in both marine and non-marine environments near a shallow epicontinental sea (Sloan, 1964; Merewether, 1983). These sedimentary strata have been subsequently eroded and remain only in localized places in Wadena County, as identified from five drill holes and well records. Cretaceous rock types vary from gray to black clay and shale to white sandstone across the county. There is little known about the Cretaceous rocks in Wadena County and they are not assigned to a named Cretaceous unit. They are designated as unit Ku (Cretaceous undifferentiated).

Cretaceous rocks mapped in Wadena County for this project appear less extensive than those depicted on the statewide bedrock map (Jirsa and others, 2011). The statewide map shows the inferred regional extent of the Cretaceous bedrock based on a calculation involving the difference between bedrock elevations and land surface elevations, whereas for this atlas, Cretaceous rocks were mapped only in locations where they were intersected and recognized in drill holes. Cretaceous sediments are relatively transparent to seismic methods, so Cretaceous rocks likely exist in many more places than identified with the methods used.

GEOLOGIC CROSS-SECTION

Computer modeling of gravity and magnetic anomaly data was conducted along a northwest–southeast profile (A–A'; Figs. 2, 3) in Wadena County to provide some insight into the third dimension—particularly relevant to interpretations of Precambrian bedrock. The geophysical model along this profile was modified slightly in Figure 3 to depict a more schematic interpretation based on what is known about the bedrock, and to highlight important features. The original model and the data on which it is based appear in digital files that accompany this geologic atlas. Constrained by rock properties data (specific gravity and magnetic susceptibility measurements) derived from similar rock types elsewhere in Minnesota (Chandler and Lively, 2011a), the model indicates that most of the anomaly sources in Wadena County extend to depths of approximately 4.3 miles (7 kilometers) below the surface. Below this depth, a uniform rock of intermediate composition, such as granodiorite (gray unit on cross section) is assumed, which is consistent with model studies in central Minnesota (Chandler and others, 2007, 2008). Significant results from modeling in Wadena County include refining the location and dip of the Vining Geophysical Lineament and better constraining the depth and extent of the Nimrod outlier sedimentary basin. Profile A–A' trends nearly perpendicular to the strike of Archean bedrock units, and coincidentally the Vining Geophysical Lineament. The model demonstrates a steep northward to vertical dip for all unit contacts across the profile and highlights the contrast in geophysical properties across the Vining Geophysical Lineament, which is consistent with its interpretation as a major terrane-bounding structural feature that likely accommodated north-directed continental accretion in the Late Archean Eon. Also apparent is an abrupt change in the thickness of the Nimrod outlier sedimentary rocks across the Vining Geophysical Lineament, indicating that the Vining Geophysical Lineament was reactivated as a normal fault during or after the deposition of the Paleoproterozoic Animikie Group.

POTENTIAL FOR MINERAL DEPOSITS IN BEDROCK

There is an elevated potential for mineral deposits in the bedrock in Wadena County. Wadena County's Precambrian bedrock is part of a large greenstone-granite terrane of the Archean Superior Province (Fig. 1). Similar, better exposed, and more fully understood rocks further north and east in the Superior Province have been known to host metallic mineral deposits, locally of extractable quality and quantity. Economic deposits in the Superior Province are commonly mafic to ultramafic in composition, and host copper-nickel, platinum group element, chromium, and titanium deposits. Mineral exploration targets also include iron formation, volcanogenic massive sulfide deposits, lode gold, and granitoid associated deposits (Poulsen and others, 1992; Jirsa and others, 2006). Wadena County has potential to host any or all of these types of mineral deposits. There is also a small potential for diamond-bearing deposits in the bedrock of Wadena County.

The thick mantle of glacial sediment covering the bedrock across all of Wadena County (Plate 5, *Depth to Bedrock*) makes exploration for potential mining ventures difficult. Sediment cover as thick as 575 feet (175 meters) eliminates utility of many geophysical exploration methods and makes exploratory drilling costly. Thus, only one mineral exploration drill hole, 264-HLV, has been drilled in Wadena County to date. This hole was drilled by a minerals exploration company (EXMIN) that has historically targeted small mafic intrusions with the potential for hosting diamonds. With improved geophysical technology, identification of potential resource deposits could prompt further mineral exploration in Wadena County.

DESCRIPTION OF AEROMAGNETIC AND GRAVITY DATA AND INTERPRETIVE PROCEDURES

Aeromagnetic data (airborne measurements of the earth's magnetic field) are sensitive to subsurface variations in the content and physical characteristics of magnetite, which is a common accessory mineral in igneous, metamorphic, and some sedimentary rocks. The aeromagnetic data used in this study were acquired by a statewide program of high-resolution surveying (Chandler, 1991). The data in Wadena County were acquired along north–south lines that were flown 1,312 feet (400 meters) apart at a mean terrain clearance of 492 feet (150 meters). The line data have been corrected for temporal variations, as well as for the effect of the regional geomagnetic field (DGRF model, National Oceanic and Atmospheric Administration, 1995), and have been interpolated into gridded data. The gridded aeromagnetic data used in this study were from a statewide, 328-foot (100-meter) spaced grid that was produced as part of a program to upgrade the aeromagnetic data base in Minnesota through reprocessing (Chandler, 2007). This statewide grid represents the magnetic anomaly data as observed at a level of 492 feet (150 meters) above the land surface. The gridded data were reduced to vertical polarization (reduce to pole, which corrects for the inclination of the earth's magnetic field, thereby placing anomalies more directly above their sources). The use of the aeromagnetic data for bedrock mapping was improved by computing first and second vertical derivative grids, which enhances the signature of magnetic sources at or near the bedrock surface.

Gravity data, which here are based on measurements taken at the land surface, are sensitive to density variations within the bedrock, which in turn reflect variations in bulk composition. The gravity data used in this study were derived from a statewide data base (Chandler and Lively, 2011b), which in Wadena County consists of stations spaced about 1 mile (1.6 kilometers) apart. The gravity data were corrected for latitude- and elevation-related effects using standard procedures (International Association of Geodesy, 1971), a sea-level datum, and a Bouguer reduction density of 2,670 kg/cc. The reduced data were subsequently used to produce a 2,625-foot (800-meter) spaced grid of the Bouguer gravity anomaly for Wadena County and surrounding areas. Following upward continuation of the Bouguer grid 1.2 miles (2 kilometers) to mitigate noise, the data were enhanced by computing a second vertical derivative grid (color part of Fig. 1). Similar to derivation of the magnetic data, the second vertical derivative operation enhances the signature of sources at or near the bedrock surface, thereby improving the utility of the gravity data for geologic mapping.

Because of their greater degree of resolution, the first vertical derivative and second vertical derivative aeromagnetic data were used to infer the majority of geologic features in the Precambrian bedrock, including contacts, dikes, and faults (Fig. 2). Rocks with strong aeromagnetic anomalies (bright white anomalies) have high magnetite content and are therefore inferred to be highly magnetic. Conversely, rocks with weak aeromagnetic signatures (dark gray anomalies) are inferred to be non- to weakly magnetic. Unit contacts were inferred around zones of distinct and internally consistent magnetic signature, whereas faults were inferred along distinct linear trends that commonly appeared to truncate magnetic signatures on either side. Dikes were inferred along narrow, linear anomalies that did not appear to offset background anomaly signatures. In areas lacking contrast in magnetic signature, the second vertical derivative gravity data were used to map contacts and faults (Fig. 2). Areas with high gravity anomalies (red to pink in color) are interpreted to be very dense, and areas with low gravity anomalies (blue to green in color) are interpreted to be relatively less dense. Because of the ambiguities of gravity and magnetic interpretation, the geologic map presented here should be used with appropriate caution, and significant revisions may occur locally, should new drill-hole data become available.

Note that the geophysical data do not portray variations in material content, thickness, or distribution of the relatively thin, flat-lying Quaternary sediments, Cretaceous strata, or saprolite.

DESCRIPTION OF MAP UNITS

PHANEROZOIC ROCKS

Mesozoic

Cretaceous

Ku **Shale and sandstone**—Gray to black shale and clay to poorly-indurated rounded to sub-rounded white quartz sandstone. Likely deposited in both marine and non-marine environments near a shallow epicontinental sea. Presence is inferred from intersection in five subsurface drill holes, three of which are scientific exploration holes drilled by the Minnesota Geological Survey (WAD-2, 1985-3, 1985-4), one of which is an exploration drill hole (264-HLV), and one of which is a private water well. Unit boundaries have been extended laterally from control points at the authors' discretion, although the unit is likely more extensive than mapped.

PROTEROZOIC ROCKS

Paleoproterozoic

Animikie Group—The Animikie Group in Wadena County is comprised of the Nimrod outlier, an erosional remnant of the larger Animikie basin. The Nimrod outlier here consists of argillite and graywacke as described below. The full stratigraphy of the Animikie Group is present further north and east in the main Animikie basin, where an argillite and graywacke sequence called the Virginia Formation overlies the Proterozoic Biwabik Iron Formation and basal Pokegama Quartzite (Jirsa and others, 2011). Unit Ᵽas in Wadena County is inferred to be equivalent to the Virginia Formation from the main Animikie basin.

Ᵽas ***Unnamed argillaceous rocks of the Nimrod outlier***—Medium to dark gray, dominantly thinly bedded to less commonly medium-bedded argillite with interbedded siltstone and graywacke. Mapped in isolated basin remnants in Wadena County primarily due to a dampened geophysical signature, which indicates the Archean basement is buried by at least approximately 1,000 feet (305 kilometers) of nearly flat-lying sedimentary rock. Based on drill core intersections of the presumably equivalent Virginia Formation in the main Animikie basin in Cass County to the east (Radakovich and Chandler, in press), the unit locally contains ankerite and euhedral pyrite in silty to sandy layers. In that area, no deformational cleavage is observed, and beds top upward and dip from 0° to 20° as indicated by local graded bedding and deformational features. Local deformation features include ball-and-pillow structure, soft sediment folding, and intrabasinal breccia layers up to 0.8 inch (2 centimeters) thick.

Kenora-Kabetogama dike swarm

Ᵽdn, Ᵽdr ***Diabase dike***—Northwest-trending, narrow, linear mafic dikes, whose trajectories are inferred in this county solely from moderate to strong linear aeromagnetic signatures anomalies. Dikes are both normally (unit Ᵽdn) and reversely (unit Ᵽdr) polarized, and are dashed where concealed by sedimentary rocks of the Nimrod outlier. Inferred from outcrop exposure of similar anomalies elsewhere in the Superior Province (Buchan and others, 1996; Schmitz and others 2006; Chamberlain, unpub. data) to be diabasic in composition and to occur as part of the approximately 2,070 Ma Kenora-Kabetogama dike swarm. Some linear anomalies with negative aeromagnetic expression, mapped here as reversely-polarized dikes, may be the result of oxidation of magnetite along fracture zones.

ARCHEAN OR PALEOPROTEROZOIC ROCKS

AⱣm **Magnetic intrusion**—Strongly magnetic, discrete, small, plug-like intrusions of uncertain age inferred to be of mafic (gabbro to diorite) to ultramafic (pyroxenite, peridotite, lamprophyre) composition. Typically range in size from less than 0.5 to 2 miles (0.8 to 3.2 kilometers) in diameter and are commonly too small to have been intersected by the statewide gravity network. May be lithologically similar to unit Agg. Map label is italicized where the unit is buried by rocks of the Animikie Group (unit Ᵽas).

AⱣg **Non-magnetic, high-gravity intrusion**—Non-magnetic to very weakly magnetic, high density, discrete, small, plug-like intrusion of uncertain age inferred to be of mafic to ultramafic composition.

ARCHEAN ROCKS

Neoarchean

Intrusive rocks—Unless stated in an individual unit description, all intrusive rocks in Wadena County are identified and described solely on the basis of aeromagnetic and density properties. The depiction and characteristics of intrusive units are thus speculative and subject to revision should additional or new data become available.

Cass batholith—Cass batholith is an informal name applied to a volumetrically extensive, unexposed suite of generally granitic rocks centered in adjacent Cass County that extends west through parts of Wadena, Hubbard, and Becker Counties (Jirsa and Chandler, 2016; Chandler and Radakovich, in press; Radakovich and Chandler, in press). May represent a northeastern continuation of the Otter Tail batholith, which is centered in Otter Tail County. On its eastern end in Cass County, the Cass batholith is fault offset against the Giants Range batholith, to which it may be equivalent.

Acg ***Granite to granodiorite***—Weakly to moderately magnetic, low gravity intrusive rocks. Inferred to be granite to granodiorite. Map label is italicized where the unit is buried by rocks of the Animikie Group (unit Ᵽas).

Acd ***Diorite to tonalite***—Moderately magnetic, very dense intrusive rocks. Inferred to be diorite to tonalite. Map label is italicized where the unit is buried by rocks of the Animikie Group (unit Ᵽas).

Acm ***Granite***—Highly magnetic, low density granitic intrusion. Drill hole 1985-3 intersected this unit, where it is composed of coarse-grained, weakly deformed, highly altered granite (Southwick and others, 1986).

Aci ***Tonalite***—Non- to weakly magnetic, dense tonalitic intrusion. Drill hole 1985-4 intersected this unit, where it is composed of brittle, fractured leucotonalite with minor hornblende-rich mafic metamorphic inclusions (Southwick and others, 1986). Map label is italicized where the unit is buried by rocks of the Animikie Group (unit Ᵽas).

Agg **Gabbro to diorite**—Strongly magnetic, very dense metamorphosed gabbroic to dioritic intrusions. Drill holes CC-32 and CC-27 in neighboring Otter Tail and Todd Counties, respectively, are located over similar anomalies and intersected hornblende metagabbro and hornblende quartz diorite, respectively (Southwick and others, 1986).

Agm **Granite to granodiorite**—Moderately to highly magnetic, generally low density intrusions with distinct boundaries implied by sharp aeromagnetic anomaly signatures. Inferred to be granite to granodiorite.

Agt **Tonalite to granodiorite**—Weakly magnetic, moderately dense intrusive rocks inferred to be tonalite to granodiorite.

Supracrustal rocks—As the Superior Province evolved during the Late Archean Eon, intense folding and faulting deformed and metamorphosed rocks extensively, particularly the supracrustal units. As a result, all supracrustal units in Wadena County (based on observations from drill core and outcrop made along strike in neighboring counties) have been metamorphosed to upper greenschist and/or lower amphibolite facies.

Acv **Calc-alkalic metavolcanic and volcaniclastic rocks**—Non- to weakly magnetic, low density rocks inferred to be calc-alkalic metavolcanic and volcaniclastic. This unit extends into adjacent Becker County to the northwest based on similar geophysical signatures, where drill core are composed of light to dark gray, intermediate calc-alkalic basalt, andesite, and dacite flows, flow breccias, and tuff. This unit forms the core of the Wolf Lake anticline in Becker County (Jirsa and Chandler, 2016).

Aif **Interbedded iron formation and mafic volcanic rocks**—Identified primarily by prominent, linear magnetic anomalies occurring within unit Amv. Inferred from stratigraphic position to be correlative with unit Aif in the Wolf Lake area in southeastern Becker County (Jirsa and Chandler, 2016). Drill core from this area of Becker County are composed of interbedded chert, magnetite, hematite, iron-carbonate, and metabasaltic tuff.

Ams **Schist of volcanic and sedimentary protolith**—Weakly magnetic, low density rocks inferred to be supracrustal, as opposed to intrusive in origin based on "tabular" or "belt-like" (as opposed to ovoid) geometry of aeromagnetic and gravity signatures. Drill core from areas with similar geophysical characteristics along strike in adjacent Cass County (Radakovich and Chandler, in press) are composed of gray to black, fine- to coarse-grained, highly foliated biotite + muscovite + quartz + chlorite + hornblende ± garnet ± staurolite schist. Metamorphosed to upper greenschist to amphibolite facies, and locally exhibits strongly developed, steeply dipping foliation and rare gneissic banding.

Amv **Mafic metavolcanic rocks**—Variably magnetic, very dense rocks inferred to be supracrustal as opposed to intrusive in origin based on "tabular" or "belt-like" (as opposed to ovoid) geometry of aeromagnetic and gravity signatures. Based on several drill holes along strike in neighboring counties (Jirsa and Chandler, 2016; Radakovich and Chandler, in press), consists of dark green to black, fine-grained basalt with minor local components of mafic hypabyssal intrusive rocks and mafic to intermediate volcaniclastic rocks, all metamorphosed to upper greenschist to lower amphibolite facies.

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