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GEOLOGIC MAP OF MINNESOTA, PRECAMBRIAN BEDROCK GEOLOGY

State Map Series **S-22**

2011

Scale 1:500,000

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This map of the Archean and Proterozoic (Precambrian) geology of Minnesota is identical with MGS State Map S-21, except it portrays an interpretation beneath Phanerozoic (Paleozoic and Mesozoic) strata inferred from geophysical maps and drill core. In many places, contacts are drawn between units of the same or similar apparent rock type (and same unit label); these are recognized as geometrically distinct, though geophysically or lithologically similar.

DESCRIPTION OF MAP UNITS

PROTEROZOIC ROCKS

The Proterozoic rocks in Minnesota are the remnants of 4 orogenic and rifting events. The Paleoproterozoic rocks contain evidence for a classic Wilson cycle of rifting and continental collision during the Geon 18 Penokean orogeny. The resulting crust was deformed, metamorphosed, and plutonized to varying degrees by the Geon 17 Yavapai and Geon 16 Mazatzal orogenies. The Yavapai Province in extreme southeastern Minnesota contains older continental crust deformed during Geon 17 and intruded by granitic rocks. Some strata assigned to the Animikie basin likely was deposited during the Yavapai event. Mesoproterozoic rocks are the product of Geon 11 continental rifting, producing volcanic and intrusive rocks of the Keweenawan Supergroup.

For brevity, approximate age dates are expressed below using the “~” symbol, and specific references to those dates are omitted. Refer to regional maps, publications, and digital files associated with this map for details. Most ages represent analyses of zircons using U-Pb methods. Somewhat less reliable ages acquired by Ar-Ar analyses of magmatic biotite or hornblende are marked with an asterisk ().*

MESOPROTEROZOIC

Keweenawan Supergroup; associated with Midcontinent rift

Mss Sandstone, siltstone, and local conglomerate; includes Hinckley Sandstone, and Fond du Lac (youngest detrital zircons ~1000 Ma) and Solar Church Formations; deposition in eolian, fluvial, and lacustrine environments.

Beaver Bay Complex and other hypabyssal intrusions

Mbd Diabase and ferrodiorite; includes Beaver River diabase, Silver Bay (~1096 Ma), Milepost 7, Leveaux, Shoepack Lake, Cabin Creek, and Monker Lake intrusions.

Mbg Gabbro, ferrogabbro, and gabbro-norite; includes Lax Lake and Cloquet Lake gabbros, Sonju Lake (~1096 Ma), Dam Five, Wilson Lake (~1096 Ma), Fourmile Lake, and Upper Manitou intrusions (~1096 Ma).

Mbf Granophyre and granite; includes Blesner Lake, Finland (~1098 Ma) and Cloquet Lake granophyres (~1095 Ma).

Mbt Troctolite, augite troctolite, and troctolitic gabbro of Houghtaling Creek troctolite (~1099 Ma).

Duluth Complex-layered series

Mlf Ferromonzodiorite forming upper contact zone.

Mlg Gabbro; includes Western Margin, Greenwood Lake, Bald Eagle (~1098), Lake One, Lake Three, Wilder Lake, and Osier Lake intrusions.

Mlt Troctolite; includes Boulder Lake, Tuscarora (~1099 Ma), Partridge River (~1098 Ma), South Kawishiwi, and part of Western Margin intrusions.

Mlc Cyclic zone; gabbro to troctolite (~1099 Ma).

Duluth Complex-anorthositic series

Mau Anorthositic intrusions and inclusions, undifferentiated (~1099 Ma).

Duluth Complex-early gabbro series

Meg Gabbroic cumulates; includes Poplar Lake (formerly Nathan's layered series) and Crocodile Lake intrusions (~1107 Ma).

Duluth Complex-felsic series

Mfg Granophyre, ferromonzodiorite, and leucogabbro; includes Mt. Weber (~1106 Ma), Whitefish Lake (~1109 Ma), Beth Lake Misquah Hills (~1106 Ma), and Cucumber Lake (~1106 Ma) granophyres, and Wine Lake monzodiorite.

Miscellaneous intrusions

Mmd Diabase, gabbro, and ferromonzodiorite; primarily sills including Endion, Lester River, Silver Cliff, Stony Point, Split Rock, Lafayette Bluff, Lake Clara-Lichen Lake, Pigeon River, and Reservation River intrusions.

Mmg Gabbroic intrusions; including Sawmill, London, Brule River, Hovland, and Pigeon Point.

Mmf Felsic intrusive rocks, granophyre; includes parts of Eagle Mtn. (~1098 Ma) and Pine Mtn. (~1095-1098 Ma) intrusions.

St. Croix Horst volcanic sequences

Mcv Chengwatana volcanic rocks; primarily mafic flows.

Mbv North Branch mafic volcanic sequence.

Mmv Minong volcanic sequence (~1095 Ma).

Mpv Powder Mill volcanic sequence (~1099 Ma).

Mfv Clam Falls volcanic sequence (~1102 Ma).

North Shore Volcanic Group-upper sequence, normal polarity

- Msl** Schroeder-Lutsen basalts; unconformably overlies units described below.
- Mns** Interflow sandstone, siltstone, and conglomerate.
- Mnu** Undifferentiated mafic to felsic lava flows; includes Lakeside, Lakewood, and Cross River lavas.
- Mnr** Rhyolite and icelandite; includes Cross River, Palisade Head (~1096 Ma), Devil Track, Maple Hill, Grand Marais, Kimball Creek.
- Mnb** Basalt and basaltic andesite; includes Leif Erickson, Lakeside (~1098 Ma), Sucker R, Larsmont, Two Harbors, Crow Creek, Gooseberry River, Gustafson Hill, Baptism River, Good Harbor Bay, Cascade River, Croftville, Red Cliff, and Marr Island lavas.

North Shore Volcanic Group-lower sequence, reversed and unknown polarity

- Mnl** Lower sequence, primarily basalt; includes Ely's Peak and Grand Portage basalts and Hovland lavas (~1108 Ma).
- Mms** Puckwunge and Nopeming Sandstones
- Mvu** Undifferentiated volcanic rocks and volcanic hornfels

Reversely polarized intrusions

- Mld** Logan intrusions; diabase and gabbro sills and dikes; locally porphyritic (~1108 and 1115 Ma).
- Mmi** Small mafic intrusive stocks; diabase, diorite, pyroxenite and gabbro; reversed magnetic polarity; includes Esko and Tamarack intrusions emplaced into unit Pas.

PALEOPROTEROZOIC or MESOPROTEROZOIC

- PMm** Mafic intrusions (gabbro, diabase) of unknown age; includes LL, BKV and Lake Washington intrusions in Meeker County.

Diabasic to Lamprophyric dikes

Trajectories largely inferred from aeromagnetic maps; includes Kenora-Kabetogama swarm (~2076 Ma), Franklin dike (~2067 Ma), and dikes of likely Mesoproterozoic age. Distribution based largely on aeromagnetic maps. Exposed thicknesses range from a few meters to more than 100 m.

- PMr** Reversely polarized; dashed where concealed by younger bedrock strata.
- PMn** Normally polarized; dashed where concealed by younger bedrock strata.
- PMu** Dikes having unknown polarity or very speculative distribution. Short segments represent dikes mapped from outcrop.

PALEOPROTEROZOIC

- Psq** Sioux Quartzite; quartzite, mudstone, and local conglomerate of fluvial and marine origin (~1760-1630 Ma; 1902±55 Ma rhyolite pebble in basal conglomerate)

Geon 17 Post-tectonic (post-Penokean orogeny) intrusions related to Yavapai orogeny

- Pmi** Mafic intrusions, pyroxenite, peridotite, gabbro and lamprophyre, defined largely by magnetic signature. One intrusion in Morrison County ~1791 Ma*, and similar intrusions cut the Foley Granite (~1774Ma).

East-central Minnesota Batholith

- Pmy** Mylonitic, gneissic, and schistose rocks of plutonic and volcanic protolith.
- Pgu** Granitic rocks undifferentiated, largely inferred from geophysical maps.

- Pgr** Granite; reddish, variably porphyritic, massive; includes St. Cloud Red (~1779 Ma), Foley (~1774, 1779 Ma), Pierz (~1779 Ma), and Pease granites, and Richmond charnockitic granite (~1772 Ma). An unnamed granite in south-central Minnesota is slightly older at ~1792 Ma.
- Pgk** Rockville Granite (~1780 Ma) and rocks inferred to be related; coarse-grained and pink to white.
- Pgd** Gray granodiorite to granite intrusions; includes Reformatory (~1783 Ma), Freedhem (~1775, 1776 Ma), Isle (~1779 Ma), and Warman (~1787 Ma) intrusions.
- Pgp** Gabbro, pyroxenite, diorite, and lamprophyre; includes Watab quartz diorite (~1780 Ma), St Wendell quartz gabbro, and an unnamed diorite (~1786 Ma).
- Pga** Gabbroic, noritic, and anorthositic intrusions.
- Pgm** Granitoid intrusions, variably magnetic; includes Ann Lake granite (~1784 Ma) and Glendorado pluton (~1788 Ma).

Hillman tonalite

- Pdt** Tonalite to leucodiorite (~1792, 1793, 1800 Ma).
- Pgt** Tonalite; locally migmatitic, with abundant biotite schist paleosome of graywacke protolith (presumably Little Falls Formation).

Geon 18 intrusions and supracrustal rocks (syn-late Penokean orogenesis)

- Pdg** Granodiorite, variably foliated; includes the Bradbury Creek (~1877-1857 Ma), and Philbrook (~1854 Ma*) intrusions.

Animikie Group

- Pas** Slate and graywacke of the Rove (~1836-1777 Ma), Virginia (~1832 Ma near base), and Thompson Formations (youngest zircons in latter ~1790 Ma).
- Pac** Virginia Formation slate and graywacke with thin carbonate layers.
- Pai** Gunflint (~1878 Ma), Biwabik, and Emily Iron Formations; locally includes thin basal sandstone and conglomerate. Capped by an irregular layer of brecciated iron-formation and ejecta derived from 1850 Ma Sudbury meteorite impact.
- Paq** Pokegama Quartzite, includes conglomerate and siliceous mudstone.

Twice-deformed metasedimentary rocks at apparent base of Animikie basin

- Pag** Graywacke and slate.
- Psi** Sulfidic iron-formation.
- Pgs** Graywacke and slate with graphitic and sulfidic zones.

Penokean intrusion

- Pml** Mille Lacs granite (~2009 Ma).

Little Falls Formation

- Pls** Schist and slate of graywacke-mudstone protolith.

Mille Lacs and North Range Groups in fold and thrust belt of Penokean Orogen (twice-deformed)

- Pms** Mille Lacs and North Range Groups and equivalent sedimentary rocks; includes Mahnomen and Rabbit Lake Formations and Trout Lake marble.
- Pif** Iron-formation in the Cuyuna North and South ranges and Mille Lacs Group; includes Trommald Formation.
- Pvs** Interlayered volcanic and sedimentary rocks.

- Pmv** Interlayered volcanic, volcanoclastic, sedimentary, and hypabyssal intrusive rocks; includes parts of Mille Lacs Group, North and South range Groups, and Glen Township Formation.
- Pmq** Dam Lake quartzite (~1868 Ma)
- Pmd** Denham Formation; lithic sandstone (reworked saprolite), marble, and mica schist (youngest detrital zircons >2000 Ma)

Sartell Gneiss

- Pgn** Quartzofeldspathic orthogneiss and schist; local metaconglomerate; age unknown.

ARCHEAN or PALEOPROTEROZOIC

- Amy** Mylonite, varied protolith; age of shearing unknown and likely protracted.
- Ami** Magnetic intrusions, undifferentiated; typically too small to ascertain gravity expression.
- APg** Granitic intrusion of unknown age; low gravity and magnetic expression.
- APd** Dioritic to granodioritic intrusion of uncertain age; moderate gravity and magnetic expression.
- APm** Gabbroic to dioritic intrusion; high to moderate gravity and magnetic signature. Includes Providence and Cottonwood intrusions in southwestern Minnesota.
- APv** Mafic volcanic and hypabyssal intrusive rocks of uncertain age; adjacent to and within Yellow Medicine shear zone.

ARCHEAN ROCKS

The Archean bedrock of Minnesota represents the southern exposed extent of the Superior Province, which is divided into 4 major tectonomagmatic terranes known as the Wabigoon, Quetico, Wawa, and Minnesota River Valley subprovinces (Figure 1). Each is a discrete fragment of oceanic and continental crust that was assembled by accretion into the Superior craton, largely completed by approximately 2.6 Ga.

NEOARCHEAN

Intrusions in all subprovinces of Superior Province

Generally discrete, unfoliated to weakly magmatically foliated or lineated plutons.

- Asd** Syenite, monzodiorite, granodiorite, and diorite; commonly hornblende- or pyroxene-bearing; includes Coon Lake, Side Lake, and Linden (~2666 Ma*) plutons of north central Minnesota.
- Agr** Granitic intrusion; includes Sacred Heart (~2592, 2603 Ma) and Ortonville granites; Shannon Lake Granite (~2674), and other intrusions having low gravity and magnetic signature.
- Agu** Granitoid intrusion; constrained solely by low gravity and magnetic signatures.
- Agm** Granite to granodiorite; variably magnetic.
- Agp** Gabbro, peridotite, pyroxenite, lamprophyre, and metamorphic equivalents; includes Oaks intrusion (~2671 Ma) in Wabigoon subprovince, and a ~ 2639 Ma lamprophyre in the western Wawa subprovince; locally defined solely by variably high gravity and magnetic signatures.
- Aqm** Monzonite, quartz monzonite, and granodiorite; includes Farm Lake phase of Giants Range batholith.
- Agd** Granodiorite to hornblende diorite, locally magmatically foliated; includes Britt Granodiorite (~2685 Ma) and other intrusions having moderate gravity and magnetic signatures.
- Ast** Saganaga Tonalite (~2690 Ma); tonalite to granodiorite; typically contains large quartz phenocrysts and autoliths.

- Adt** Tonalite-leucodiorite plutons; includes Grygla, Red Lake Falls and other plutons having low magnetic and gravity signatures.
- Aqp** Porphyritic quartzofeldspathic dikes; typically hypabyssal intrusions associated with felsic volcanic sequences.

Foliated to gneissic intrusive complexes and components of batholiths

- Agf** Leucogranite; occurs along Yellow Medicine Shear Zone and elsewhere, primarily in batholithic settings.
- Agt** Foliated to gneissic tonalite, granodiorite and diorite; includes Lookout Mountain tonalite (~2718 Ma) of the Giants Range batholith and other intrusions within batholithic complexes defined by low-moderate gravity signature with magnetic foliation apparent from aeromagnetic maps
- Agn** Granitic to granodioritic orthogneiss; includes McGrath Gneiss (~2752±15, 2557) and unnamed units.
- Ags** Schist and tonalitic to granodioritic paragneiss; typically marginal to large batholithic complexes.

Metamorphic and intrusive rocks of Quetico subprovince

Composed of biotite-plagioclase schist, granitoid intrusions, and migmatite. Schist was derived from graywacke deposited ~2698-2692 Ma in an accretionary prism during collision of the Wawa subprovince island arc to the south, with the Superior craton (superterrane) to the north (Shebandowanian orogeny*). This was followed by multiple episodes of intrusion, migmatization, metamorphism, and deformation. Metamorphic grade is symmetrical along the axis of the subprovince, with greenschist grade at the margins and amphibolite to granulite facies near the center.

- Aql** Lac La Croix Granite; pink biotite granite that is variably magnetic and locally pegmatitic (~2665-2667 Ma).
- Aqg** Granite-rich migmatite containing neosome of variably magnetic biotite granite like the Lac La Croix.
- Aqt** Migmatite dominated by tonalitic to granodioritic neosome.
- Aqs** Biotite schist of graywacke protolith, and schist-rich migmatite.
- Aqa** Amphibolitic schist and gneiss.

Supracrustal and hypabyssal intrusive rocks of Wawa and Wabigoon subprovinces

Strata are subdivided approximately by their apparent temporal relationship to three major periods of deformation; the first (D₁) at about 2695 Ma, which may be equated with the Shebandowanian** orogeny in adjacent Ontario; the second (D₂) at about 2680 Ma occurred during the Minnesotan orogeny and produced regional fabrics, folds, and prograde metamorphism to greenschist-amphibolite grade. The former may represent collision of the Wawa subprovince with the composite Superior superterrane to the north. The latter can be attributed to collision of the Minnesota River Valley subprovince with the Superior superterrane along a suture known as the Great Lakes Tectonic Zone. A D₃ event is manifest in the Quetico subprovince as broad folds involving D₂ fabrics, and elsewhere by faulting.

Post-D₁/Pre-D₂ Alkalic volcanic and successor-basin deposits

- Asc** Conglomerate, lithic sandstone, and graywacke, undifferentiated; includes Midway sequence, Seine Group, and a part of the Knife Lake Group known as Ogishkemuncie conglomerate that contains clasts of ~2690 Ma Saganaga Tonalite. Deposition of alluvial fan and fluvial sediments occurred in fault-bounded basins.
- Aks** Knife Lake Group volcanogenic lithic sandstone, conglomerate, siltstone, graywacke, and slate.

- Akc** Knife Lake Group conglomerate composed largely of hornblende-bearing volcanic rocks.
Akv Knife Lake Group, hornblende-phyric volcanic flows, breccia, and tuff.

Pre-D₁ Metavolcanic, metasedimentary, and hypabyssal intrusive rocks

- Ams** Schist of sedimentary protolith, metamorphosed to upper greenschist to amphibolite facies.
Aif Iron-formation; includes Soudan Iron Formation and many unnamed units.
Asg Volcanogenic graywacke and mudstone; includes Lake Vermilion Formation.
Avs Volcaniclastic rocks of felsic to intermediate composition.
Acv Calc-alkalic volcanic and volcaniclastic rocks.
Aag Mafic to ultramafic hypabyssal intrusive complexes composed of gabbro, pyroxenite, diorite and anorthosite; includes Mentor and Deer Lake complexes, intrusions of the Newton Lake Formation, all within Wawa subprovince; and UBD intrusion (~2685-2695 Ma*) in Wabigoon subprovince.
Amv Mafic metavolcanic rocks; includes minor volcaniclastic and hypabyssal intrusive rocks metamorphosed to greenschist to lower amphibolite facies; includes Ely Greenstone (~2722 Ma).
Auv Mafic to ultramafic (komatiitic) volcanic rocks; includes the Newton Lake Formation and Deer Lake sequence.
Amm Interlayered metavolcanic, volcaniclastic, and hypabyssal intrusive rocks metamorphosed to amphibolite facies.

MESOARCHEAN to PALEOARCHEAN

Montevideo, Morton, and related gneisses in the Minnesota River Valley subprovince of west-central and southwestern Minnesota. The subprovince is divided into distinct blocks separated by faults and structural discontinuities defined largely by geophysical maps. The gneissic rocks, dated at ~3524-3485 Ma, were cut by tonalite at ~3422 Ma, granodiorite at ~3385-3370 Ma, and granite at ~2604 Ma (including the Sacred Heart Granite—labeled as unit Agr). Significant metamorphic events are recorded at ~3300, ~3140, and ~2600 Ma.

- Amg** Granitic orthogneiss and migmatite; geophysical maps imply this unit intruded other gneisses.
Amt Foliated to gneissic tonalite and granodiorite.
Amd Granitoid gneiss with dioritic to amphibolitic enclaves; produces moderately high and varied gravity and magnetic signatures.
Amn Amphibolitic to dioritic gneiss.

** The terms “Shebandowanian orogeny” and “Minnesotan orogeny” represent subdivisions of what was formerly known as the Kenoran orogeny (ala., Percival and others, 2006, Canadian Jour. E. Sci. **43**:1085-1117).

STRUCTURE SYMBOLS

Geologic contact—dashed where concealed by younger bedrock strata.

Fault—strike- or dip-slip kinematic sense; steeply dipping.

Thrust fault, or structural or geophysical discontinuity interpreted to have involved thrust displacement—teeth on inferred upper plate.

CAPTION FOR FIGURE 1

Figure 1. Terrane map of Precambrian bedrock showing subprovinces of the Archean Superior Province (iron-formation shown in red), significant elements of Paleoproterozoic bedrock, the Mesoproterozoic Midcontinent rift, and mafic dikes (gray) of Paleoproterozoic and Mesoproterozoic age. Shaded areas are covered by Phanerozoic strata.