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Harvey Thorleifson, Director

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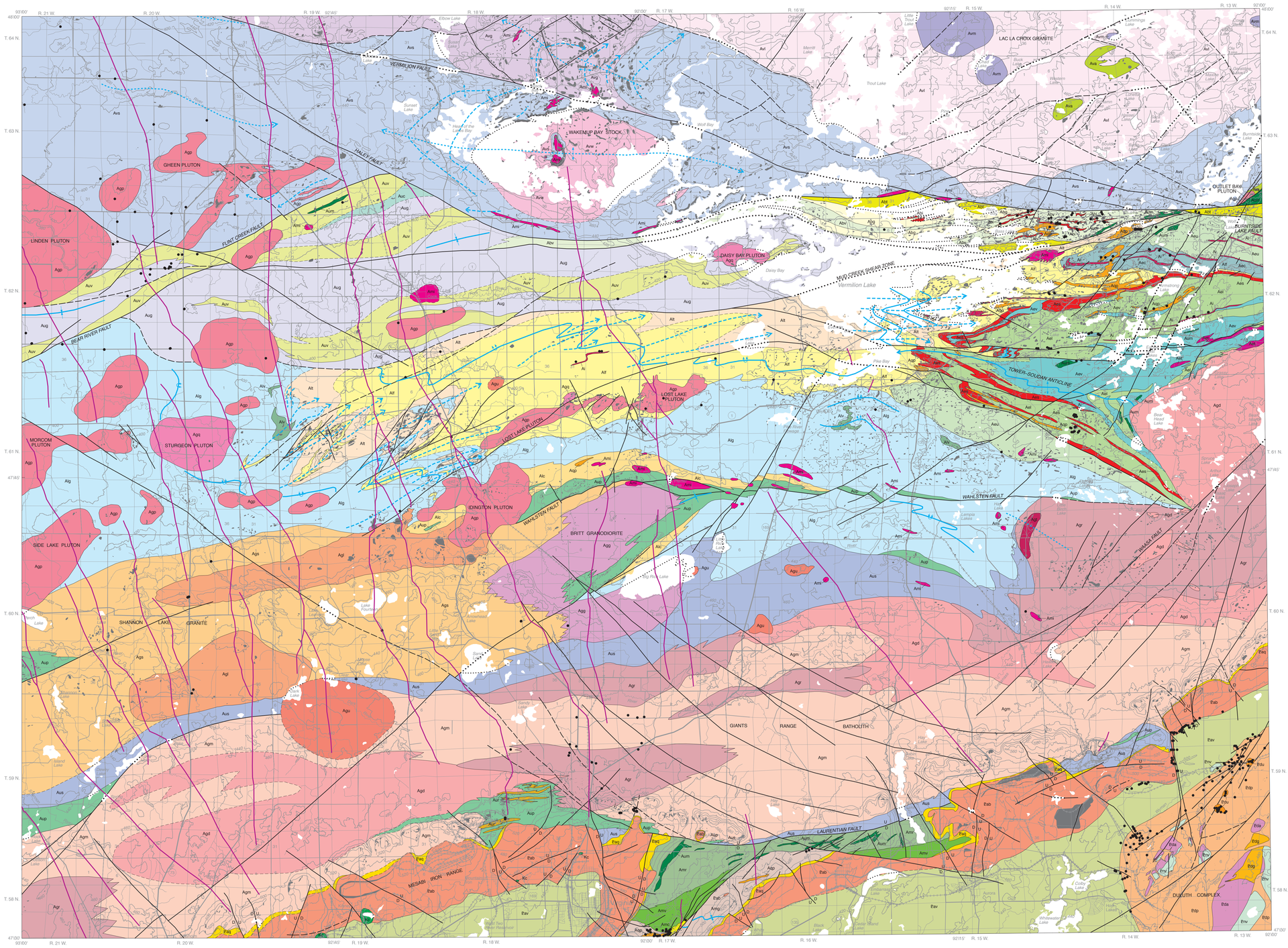
MISCELLANEOUS MAP SERIES
MAP M-141

Bedrock Geology, Vermilion Lake Quadrangle



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
1 0 1 2 3 4 5 MILES
1 0 1 2 3 4 5 6 7 8 KILOMETERS
CONTOUR INTERVAL 20 METERS

GIS compilation and cartography
by R.S. Lively and Timothy E. Wahl
Edited by Lori Robinson

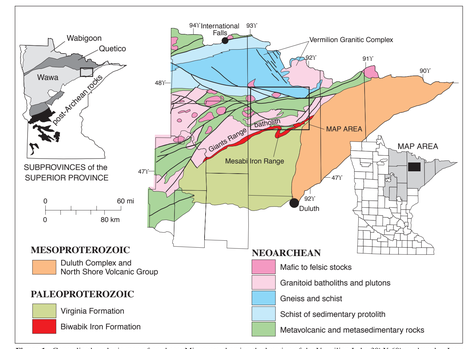


Figure 1. Generalized geologic map of northeast Minnesota showing the location of the Vermilion Lake 30' X 60' quadrangle. Inset maps show location index and subprovinces of the Archean Superior Province.

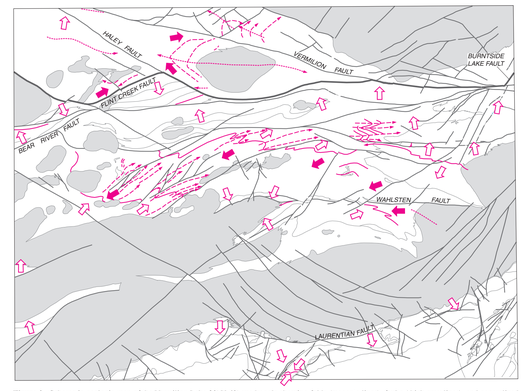
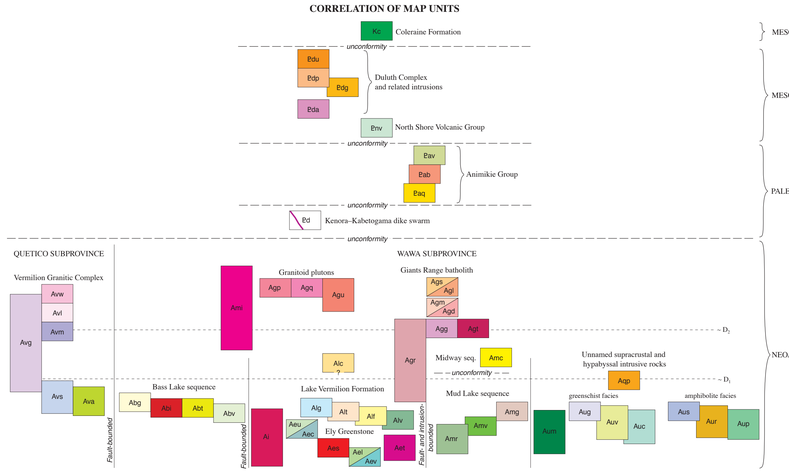


Figure 2. Schematic geologic map of the Vermilion Lake 30' X 60' quadrangle showing folds (magenta lines), faults (thick gray lines), and generalized stratigraphic facing within Archean supracrustal sequences. The bold fault line in the upper part of the map approximates the boundary between the Quetico and Wawa subprovinces. Major intrusions are gray. Open arrows show the horizontal younging direction in steeply dipping strata and upright facing where dips are shallower. Solid arrows indicate downward stratigraphic facing.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

MESOZOIC

Cretaceous Coleraine Formation

Kc — ***Conglomerate and sandstone*** — Basal conglomerate composed largely of iron-formation clasts, overlain by hematite-cemented quartz arenite.

MESOPROTEROZOIC

Duluth Complex — Multi-phase intrusive igneous suite of the 1.1 Ga Midcontinent Rift System.

Pdu — ***Ultramafic, oxide-rich intrusions*** — Coarse-grained to pegmatitic clinopyroxenite, peridotite, and dunite enriched in Fe-Ti oxide; oxide contents vary from 15 to nearly 100 percent.

Pdp — ***Partridge River intrusion*** — Composed predominantly of medium- to coarse-grained, variably layered olivine-plagioclase cumulate and troctolite containing inclusions of volcanic hornfels and anorthositic rocks. The basal contact zone is composed of olivine gabbro, augite troctolite, gabbronorite, and norite. Forms a southeast-dipping intrusion at the base of the Duluth Complex.

Pdg — ***Olivine gabbro*** — Coarse-grained, subophitic to intergranular olivine gabbro to olivine-poor oxide gabbro.

Pda — ***Anorthositic series subsuite of the Duluth Complex*** — Composed predominantly of medium- to coarse-grained leucocratic troctolite to gabbro.

North Shore Volcanic Group

Pnv — ***Volcanic and sedimentary hornfels*** — Sequence of metamorphosed tholeiitic plateau lava flows and minor interflow sedimentary rocks. Forms isolated inclusions within the Duluth Complex and also forms its hanging wall.

PALEOPROTEROZOIC

Animikie Group

Pav — ***Virginia Formation*** — Interbedded carbonaceous shale, mudstone, siltstone, and feldspathic graywacke.

Pab — ***Biwabik Iron Formation*** — Laminated to thin-bedded, iron-rich rock composed of layers that are principally chert, iron silicate minerals, iron oxide minerals (hematite or magnetite), iron carbonate, or combinations of these phases. A U-Pb zircon date from a tuffaceous unit in the Gunflint Iron Formation, which is inferred to be equivalent, yielded an age of 1,878.3 ± 1.3 Ma (Fralick and others, 2002).

Paq — ***Pokegama Quartzite*** — Includes quartzite, quartz-rich siltstone, shale, and local basal conglomerate.

Kenora–Kabetogama Dike Swarm

Pd — ***Diabase and gabbro*** — Aphanitic to coarse-grained; thickness varies from several feet to 328 feet (100 meters). Dike trajectories were inferred from aeromagnetic and topographic trends in areas of scant outcrop. Coextensive with the Fort Frances dike swarm in Ontario.

NEOARCHEAN

This map depicts Neoarchean bedrock within the Wawa and Quetico subprovinces of the Superior Province (Fig. 1). The boundary between subprovinces is defined by a metamorphic and lithologic break that corresponds with (from west to east) the Flint Creek, Haley, Vermilion, and Burntside Lake faults. The faults juxtapose volcanic and clastic strata of the Wawa subprovince metamorphosed to greenschist grade on the south, and dominantly graywacke of amphibolite grade in the Quetico subprovince to the north. Much of the tectonostratigraphic distinction between various geologic elements in both subprovinces is based on fabrics that resulted from three major phases of metamorphism and deformation, denoted D_1, D_2, and D_3 (approximate relative timing is shown on the Correlation of Map Units). In the Wawa subprovince, D_2 involved generally soft-sediment deformation of graywacke sequences (in some localities forming large nappe structures), and tilting, broad folding, and thrust imbrication of the more rigid volcanic strata. By contrast, D_2 in the Quetico subprovince produced essentially bedding-parallel schistosity in graywacke. D_3 deformation accompanied regional metamorphism to greenschist to amphibolite facies, and produced widespread foliation, lineation, and localized folding and strike-slip faulting in both subprovinces—all the result of northwest–southeast-directed transpression. U-Pb dates of intrusions that bracket D_2 place the event between about 2,674 and 2,685 Ma (Boerboom and Zartman, 1993). D_3 affected all Neoarchean bedrock, and is manifest in broad folding of Quetico subprovince rocks, but only partitioned deformation (crenulation, folds, and faults) in most rocks of the Wawa subprovince.

Unnamed mafic intrusions, Wawa and Quetico subprovinces

Ami — ***Mafic intrusions*** — Includes lamprophyre, diorite, and diabase, possibly of more than one age; typically cuts D_2 deformation fabrics; intrusions in the Quetico subprovince display weak and localized fabric development and broad folding attributed to D_3 deformation.

Vermilion Granitic Complex, Quetico subprovince

Avw — ***Tonalite to diorite of the Wakemup Bay stock*** — Light to dark gray, medium-grained, biotite-bearing.

Avl — ***Lac La Croix granite and granite-rich migmatite*** — Medium- to coarse-grained leucocratic granite that grades locally into granite-rich migmatite with increasing proportions of biotite-plagioclase schist inclusions, especially near contacts with unit Avs.

Avg — ***Granite-rich migmatite*** — Composed of varied percentages of biotite schist and granitic phases including tonalite, granodiorite, granite, and pegmatite; weakly to moderately magnetic.

Avm — ***Hornblende monzodiorite*** — Medium- to coarse-grained intrusive rock, weakly to prominently foliated, typically of mottled appearance owing to the presence of black hornblende in amounts of 5 to 20 percent. Intruded by dikes and larger masses of Lac La Croix granite.

Avs — ***Biotite schist, locally migmatitic*** — Consists of plagioclase-quartz-biotite schist of graywacke protolith; metamorphosed to amphibolite facies; typically non-magnetic.

Ava — ***Amphibolite schist*** — Fine- to medium-grained; in part derived from volcanic protolith.

Granitoid plutonic rocks, Wawa subprovince — Discrete plutons and stocks that vary from granite to syenite to diorite, are locally magnetic, and typically multi-phase intrusions containing mafic enclaves. Late to post-tectonic with respect to D_2 deformation.

Agp — ***Quartz-poor to quartz-absent intrusions*** — Pyroxene and hornblende-bearing syenite, monzonite, monzodiorite, and diorite; includes the Gheen, Linden, Lost Lake, Outlet Bay, Idington, Side Lake, and Morcom plutons.

Aqq — ***Quartz-bearing intrusions*** — Quartz monzonite, quartz diorite, granodiorite, and syenogranite; includes the Sturgeon and Daisy Bay plutons.

Agu — ***Granitic intrusions having unknown or poorly known attributes*** — Defined largely by geophysical signatures.

Giants Range batholith, Wawa subprovince — Multi-lithic batholith containing distinct intrusions and phases emplaced both during and after D_2 deformation.

Ags — ***Shannon Lake granite*** — Gray to pink, medium- to coarse-grained, two-mica granite; typically non-magnetic; predates D_2 deformation; U-Pb age of 2,674 ± 5 Ma (Boerboom and Zartman, 1993).

Agl — ***Shannon Lake granite, inclusion-bearing phase*** — As above, but containing inclusions of the Idington pluton (unit Agp), granodiorite (unit Agg), and Lake Vermilion Formation (units Alc and Alg); variably magnetic.

Agm — ***Quartz monzonite and monzodiorite*** — Pink to dark greenish-gray, hornblende-bearing, coarse-grained, and variably porphyritic; variably magnetic; includes units previously mapped as Pike Mountain monzodiorite and Mesabi granite (Jirsa and Morey, 2003), and the Farm Lake facies (Green and others, 1966).

Agd — ***Quartz monzonite, monzodiorite, and monzogranite*** — Pinkish-gray, medium- to coarse-grained, hornblende-bearing, variably porphyritic; typically non-magnetic; includes parts of the Farm Lake facies and a large body in the axial core of the Tower–Soudan anticline (Jirsa and others, 2001).

Agg — ***Britt granodiorite*** — Pinkish-gray to greenish-black, medium- to coarse-grained, hornblende-bearing, variably lineated; inferred to have been emplaced synchronously with D_2 deformation; U-Pb age 2,685 ± 4 Ma (Boerboom and Zartman, 1993). Includes minor tonalite.

Agi — ***Tonalite to leucogranite*** — Intruded unit Agr; also occurs as multiple, deformed intrusions into unit Agr that are too small to be depicted at this scale.

Agr — ***Tonalite to granodiorite*** — Foliated and variably modally layered; typically biotite- and/or hornblende-bearing; components inferred to be syn- and pre-D_2; locally contains inclusions of schist (unit Aus) and dioritic enclaves; unit includes the Lookout Mountain tonalite (Jirsa and others, 1998) and Embarrass tonalite.

Supracrustal and hypabyssal intrusive rocks, Wawa subprovince—The rock units described below are assigned to largely informal lithostratigraphic units that are grouped according to their areas of exposure (shown on the Correlation of Map Units, separated by vertical lines). Portions of these strata probably are equivalent; however, their segmentation by faults, intrusions, and regions of poor exposure, and the paucity of detailed geochronologic data preclude definitive correlation between areas. The stratigraphic facing of supracrustal sequences is shown generally on Figure 2.

Bass Lake sequence — Informal lithostratigraphic sequence that may correlate with parts of the Newton Lake Formation and Knife Lake Group to the northeast, from which it is separated by a complex network of faults. Metamorphosed to greenschist facies.

Abg — **Graywacke, slate, tuffaceous graywacke, and local reworked tuff.**

Abi — **Iron-formation**—Chert-magnetite; interlayered on all scales with various volcanic and volcaniclastic strata.

Abt — **Volcanic rocks of tholeiitic to komatiitic composition**—Typically dark green, massive to pillowed lavas and associated autobreccias.

Abv — **Volcanic rocks of interlayered tholeiitic and calc-alkalic composition**.

Iron-formation in the Ely Greenstone and Lake Vermilion Formation

Ai — **Iron-formation**—Discontinuous layers of chert-, magnetite-, hematite-, and locally sulfide-bearing iron-formation; includes stratigraphic horizons of iron-rich volcanic autobreccia; delineated locally by aeromagnetic and drilling data.

Lake Vermilion Formation — Complexly interbedded strata that vary and locally grade from first-cycle felsic (calc-alkalic) volcaniclastic rocks, through rocks having evidence of variable reworking, to mixed-source graywacke. Typically metamorphosed to greenschist facies, though local nodes of higher grade exist.

Alc — **Conglomerate**—Polymictic strata containing clasts of granodiorite, tonalite, graywacke, siltstone, felsite, tuff, and basalt. May represent younger successor-basin sediments deposited along a fault zone.

Alg — **Graywacke, slate, and siltstone**—Medium to dark gray, mixed lithologic source; displays graded bedding and other primary textures. Associated fine-grained beds are dark gray.

Alt — **Tuffaceous graywacke**—Light to medium gray; coarser grains are composed almost entirely of white-weathered feldspar; graded bedding is well developed locally. Associated shale and siltstone layers are dark medium gray.

Alf — **Felsic tuff and reworked tuff**—Typically white-weathered, fine-grained to locally coarse-grained and clast-rich; thinly bedded to massive; poorly developed graded bedding.

Alv — **Volcanic rocks**—Isolated lenses of variably pillowed, dark greenish-gray, tholeiitic lavas.

Ely Greenstone—upper member

Aeu — **Tholeiitic volcanic rocks**—Dark green, massive to pillowed, locally pyroxene-phyric lava flows.

Aec — **Calc-alkalic volcanic rocks**—Dacite, andesite, and basalt, together with derived volcaniclastic strata and minor tuffaceous graywacke; includes the Gafvert Lake sequence (Jirsa and others, 2001); locally transitional with tuffaceous units of the Lake Vermilion Formation. In contrast with tholeiitic flows, the calc-alkalic rocks typically are plagioclase-phyric and lighter colored (medium greenish-gray to light bluish-gray), and individual flows contain a larger proportion of fragmental rocks (autobreccia).

Ely Greenstone—Soudan iron-formation member

Aeis — **Iron-formation**—Consists of alternating layers of chert, magnetite, hematite, jaspilite, and varying proportions of interbedded volcanic strata; transitional with volcanic units in the lower member of the Ely Greenstone.

Ely Greenstone—lower member

Aet — **Tonalite**—Medium-grained, biotite- and hornblende-bearing; local modal layering; the presence of moderate foliation and chemical similarity with calc-alkalic rocks in the upper Ely Greenstone implies it may be a subvolcanic "feeder" intrusion.

Ael — **Tholeiitic volcanic rocks**—Dark greenish-gray, massive to pillowed lava flows, separated locally by thin and discontinuous lenses of iron-formation—particularly the stratigraphically higher areas.

Aev — **Calc-alkalic volcanic rocks**—Medium gray to bluish-gray, plagioclase-phyric; consist of pillowed flows that have abundant hyaloclastite matrix and thick autobreccia. One dacite yielded a U-Pb age of 2,722 ± 0.9 Ma (Peterson and others, 2001).

Midway sequence

Amc — **Conglomerate and trachyandesite flows**—Conglomerate and lithic sandstone composed of detritus derived from the Mud Lake sequence and clasts of hornblende-phyric trachyandesite. Local fragmental flows of trachyandesite are interdigitated with the conglomerate and sandstone and contributed abundant clasts to superjacent conglomerate beds. Forms a south-facing homoclinal sequence deposited on eroded folds attributed to D_2 deformation and was foliated by D_2 (Jirsa, 2000).

Mud Lake sequence — Sequence of volcanic and associated intrusive rocks overlain by graywacke within a broad, more or less symmetrical syncline attributed to D_2 deformation. Although strongly foliated locally by D_2, metamorphic grade is comparatively low, varying from zeolite to lower greenschist facies.

Amg — **Graywacke and slate**—Gray to light brown, fine- to medium-grained; graded bedding is common.

Amv — **Tholeiitic volcanic rocks**—Dark green, massive, pillowed, and locally autobrecciated flows.

Amr — **Calc-alkalic volcanic rocks**—Mafic to intermediate composition; medium to light greenish-gray; section includes thick fragmental units that are reworked into volcanic conglomerates toward their tops.

Unnamed supracrustal and hypabyssal intrusive rocks—Poorly exposed units having a variety of apparent ages, though generally correlative with lithologically similar rocks in the district. Metamorphic grades vary from greenschist (units Agp, Aum, Aug, Auv, and Auc) to amphibolite facies (units Aus, Aup, and Aur).

Aqp — **Quartz-feldspar porphyry**—Light gray to gray rock that contains rare to abundant megascopic phenocrysts of quartz and/or sodic plagioclase. A U-Pb zircon date from a porphyry dike in the Bass Lake sequence is 2,683 ± 1.4 Ma (Peterson and others, 2001).

Aum — **Metagabbroic rocks**—Dark greenish-gray, presumed hypabyssal sills and dikes related to subjacent volcanic rocks.

Aug — **Graywacke and slate**—Undifferentiated.

Auv — **Tholeiitic volcanic rocks**—Undifferentiated.

Auc — **Calc-alkalic volcanic rocks**—Undifferentiated

Aus — **Schist of sedimentary protolith**—Biotite-plagioclase-quartz schist and lesser migmatite; exposed discontinuously north and south of the Giants Range batholith; locally in fault contact with lower grade, but inferred equivalent strata; sedimentary textures are preserved in some outcrops.

Aur — **Schist of gabbroic intrusive protolith**—Medium- to coarse-grained amphibolitic rocks, locally having relict ophitic to diabasic textures.

Aup — **Schist of mafic-intermediate volcanic protolith**—Typically fine- to medium-grained, strongly lineated, amphibolitic rocks containing locally recognizable pillows and other primary volcanic structures.

MAP SYMBOLS

Geologic contacts
- Approximately located.
- Inferred from geophysical data.
- Concealed.

Faults—Letters indicate relative vertical displacement; up (U), down (D).
- Approximately located.
- Inferred largely from geophysical data and topography.
- Concealed.

Axial surface traces of folds in Archean rocks—Note that outcrop-scale structures are omitted because they cannot be meaningfully depicted at this scale. Users requiring such data should consult the maps on which this compilation is based. General stratigraphic facing of supracrustal sequences is shown schematically on Figure 2 and can be inferred locally from fold axes shown on this map. The axes of three generations of folding are presented here, denoted F_1, F_2, and F_3.

F_1 fold—Inferred largely from structural facing in the plane of D_2 cleavage; the general direction of plunge is shown where it can be established; upright anticline, syncline; inclined anticline, syncline.

F_2 fold—Typically vertical to steeply inclined fold axes; the direction of plunge is shown; antiform, synform. F_2 fold forms may be anticlinal (outward younging) or synclinal (inward younging) depending on their position locally on the limbs of inclined F_1 folds.

F_3 fold—Steeply dipping fold axes; the direction of plunge is shown locally; antiform.

Outcrop—Includes areas of closely spaced, small outcrops.

Drill hole—Location of exploration and scientific test holes. Not shown along much of the Mesabi Iron Range.

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Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the Minnesota Geological Survey does not warrant or guarantee that there are no errors. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, and it should not be used to guide engineering-scale decisions without site-specific verification.

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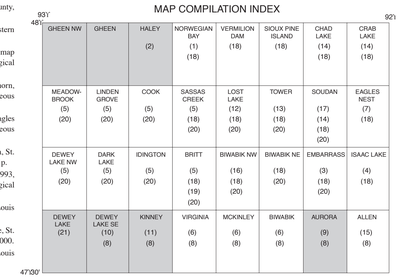
MAP COMPILATION INDEX



Index of 7.5-minute quadrangles that constitute the Vermilion Lake map showing numbers (in parentheses) that correspond to sources of previous mapping, as listed in the references. The primary compilation reference is listed first in each quadrangle. Shaded maps represent areas compiled largely from previously unpublished work by the authors between 1990 and 2002.

BEDROCK GEOLOGY OF THE VERMILION LAKE 30' X 60' QUADRANGLE, NORTHEAST MINNESOTA

Compiled by

Mark A. Jirsa and Terrence J. Boerboom

2003

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