UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
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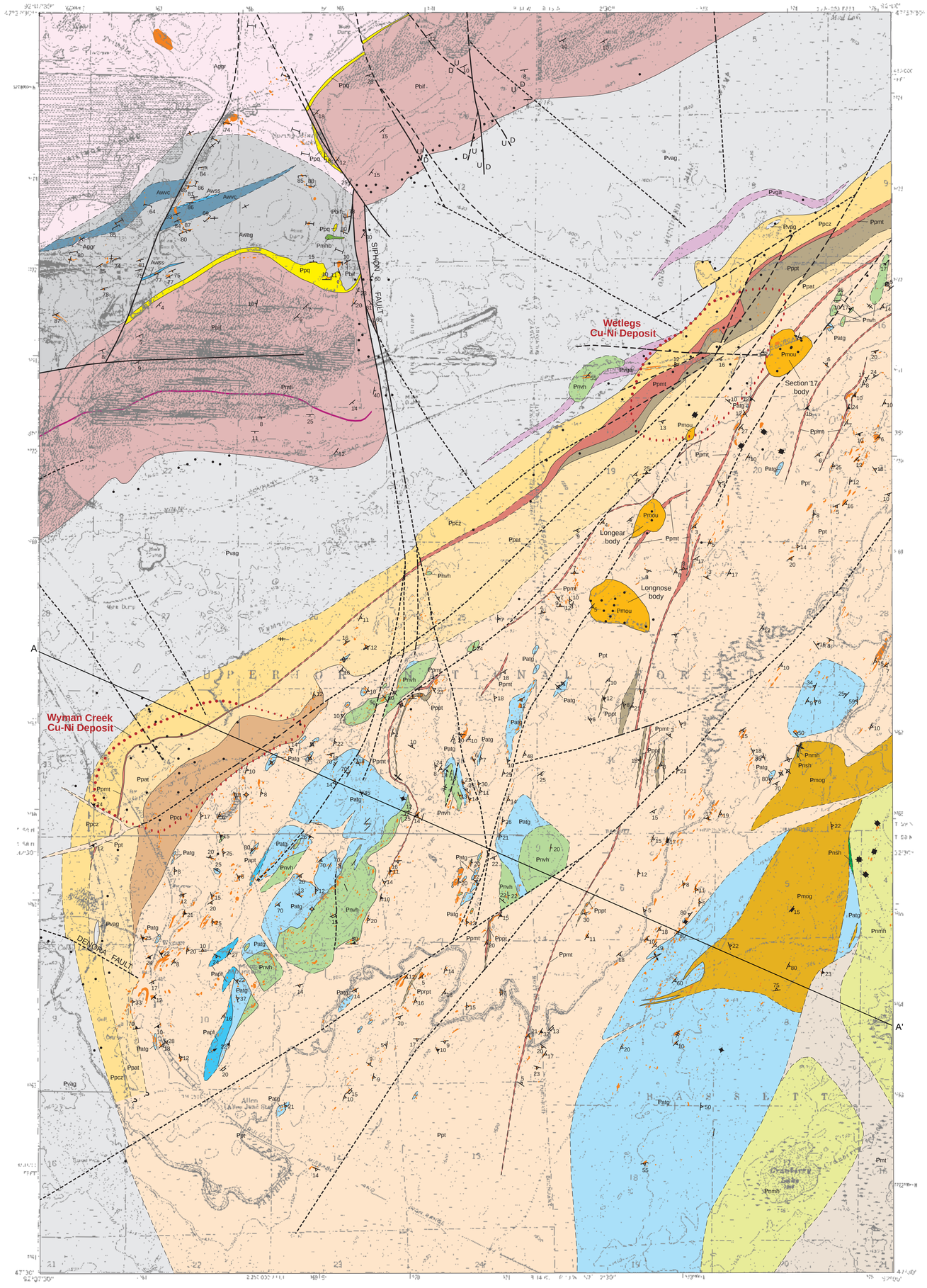
MISCELLANEOUS MAP SERIES
MAP M-91
Bedrock Geology, Allen Quadrangle



Base modified from U.S.Geological Survey
1996 Digital Raster Graphic of the Allen
1:24,000 quadrangle (1962; photorevised 1984)

Universal Transverse Mercator Projection, grid zone 15
1927 North American Datum

APPROXIMATE MEAN DECLINATION, 1998

SCALE 1:24 000

1 1/2 0 1 MILE

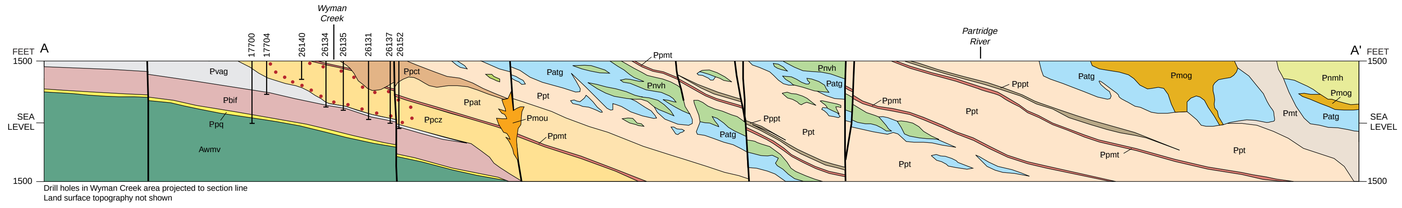
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRANGLE LOCATION

GIS compilation and cartography
by Timothy E. Wahl

Cartographic design by R. S. Lively



Drill holes in Wyman Creek area projected to section line
Land surface topography not shown

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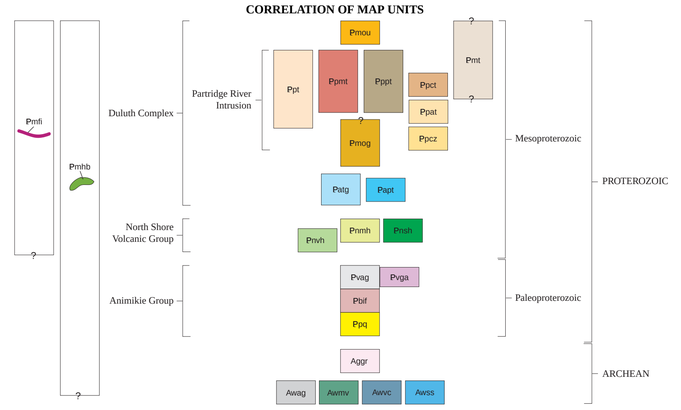
BEDROCK GEOLOGIC MAP OF ALLEN QUADRANGLE, MINNESOTA

By
Mark J. Severson and James D. Miller, Jr.

1999

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

MESOPROTEROZOIC

DULUTH COMPLEX—Multiply intruded igneous suite of 1.1–Ga Midcontinent rift system; generally subdivided into four major subsuites or series—early gabbroic, felsic, anorthositic, layered—on basis of lithology, internal structure, and intrusive relationships (Miller and Ripley, 1996). Rocks of layered and anorthositic series, as well as rocks of unknown affiliation, are represented in quadrangle.

LAYERED SERIES—Multiply intruded subsuite of Duluth Complex composed of mafic igneous rocks that display stratiform internal structure, cumulate rock textures, and compositional layering indicative of in-situ differentiation, and that typically compose discrete mafic layered intrusions. Most layered-series rocks in Allen quadrangle are of the Partridge River intrusion.

Partridge River intrusion—Southeast-dipping mafic layered intrusion forms northwestern margin of Duluth Complex. Troctolitic (olivine-plagioclase) cumulates predominate in quadrangle; locally contain inclusions of various anorthositic rocks and volcanic hornfels. Drill-hole intersections of poorly exposed lower contact indicate Virginia Formation and locally downdip Biwabik Iron Formation form footwall within 5 km of inferred trace of basal contact (Severson and Hauck, 1997). However, geophysical modeling (Chandler and Lively, 1998) suggests the basal contact farther down dip steepens and cuts Archean basement. Core indicates lower part of intrusion divisible into multiple stratiform units traceable along strike (Units I-VII of Severson and Hauck, 1990, 1997). These units are difficult to recognize unambiguously in outcrop and are not adopted here. Exploratory drilling identified two low-grade Cu-Ni sulfide mineralization prospects (Wyman Creek, Wetlegs) and several Fe-Ti oxide prospects (Longnose, Longear, Section 17, and some smaller occurrences) in quadrangle.

Ppt Troctolite—Homogeneous, medium- to medium-coarse-grained, poorly to moderately foliated, variably leucocratic, ophitic troctolite to augite troctolite. Contains 70–85% lath-shaped, labradoritic plagioclase (An67–53), 10–25% anhedral granular olivine (Fo66–54), 1–8% ophitic to subophitic augite (En'68–79), and 1–3% anhedral granular to poikilitic Fe-Ti oxide; minor accessory phases include biotite, orthopyroxene, hornblende, apatite, and sulfide. Significant modal layering only in vicinity of melatroctolite (map unit **Ppmt**) intervals. Primary minerals typically display rare to minor deuteric alteration. Unit forms greatest volume of rock in intrusion; includes Units V, VI, VII, and VIII of Severson and Hauck (1990, 1997).

Ppmt Melatroctolite—Modally layered, medium- to fine-grained, moderately to well-foliated, melatroctolite, feldspathic dunite, and troctolite. Rarely exposed in outcrop, but core indicates melatroctolite units common in Partridge River succession. Layering varies from intermittent to rhythmic; individual layers range from a few centimeters to several meters thick. In core, cyclical graded layering common where finer grained, olivine-rich rocks grade upward to medium-grained troctolite and, locally, augite troctolite. Olivine-rich intervals extensively serpentized. Olivine and plagioclase compositions consistently more primitive (Fo72–66, $An_{68–64}$) than other Partridge River rock types. Lowest melatroctolite unit equivalent to Unit II of Severson and Hauck (1990, 1997); other units higher in section define bases of Units V, VI, and VII.

Ppct Coarse-grained troctolite—Homogeneous, coarse- to very coarse grained, poorly laminated to decussate, ophitic, leucocratic troctolite to augite troctolite. Similar in mode and texture to troctolite (map unit **Ppt**); differs by being consistently coarse grained, poorly foliated, and leucocratic. Plagioclase symplectite common in thin section. Equivalent to lower part of Unit V of Severson and Hauck (1990, 1997) where it thickens in Wyman Creek area.

Ppat Augite troctolite—Homogeneous, coarse- to medium-coarse-grained, poorly to moderately foliated, ophitic augite troctolite. Composed of 65–75% plagioclase (An64–56), 10–15% subhedral granular to ameboidal olivine ($Fo_{62–55}$), 5–15% ophitic augite ($En_{74–68}$), 3–8% Fe-Ti oxide, and minor accessory phases, including biotite, orthopyroxene, sulfide, amphibole, and apatite. Shows local moderate deuteric alteration. Occurs as 100–170-m-thick interval equivalent to Unit IV of Severson and Hauck (1990, 1997) in narrow gradational contact with poikilitic troctolite rocks below (map unit **Pppt**) and in broadly gradational contact above with augite-poor troctolites of map units **Ppct** or **Ppt**. In core, base of unit commonly marked by thin (< 8 m) melatroctolite layer.

Pppt Poikilitic troctolite—Fine- to medium-grained, decussate, poikilitic leucotroctolite to augite troctolite. Contains 65–85% tabular plagioclase ($An_{65–56}$), 15–25% poikilitic olivine ($Fo_{57–53}$) as moderately dense oikocrysts (1–3 cm), and 1–15% ophitic augite ($En_{70–67}$). Distinctive mottled appearance due to irregularly distributed olivine oikocrysts. Unit present as stratiform layers of variable thickness and lateral continuity at several stratigraphic levels in Partridge River intrusion, most commonly above melatroctolite (map unit **Ppmt**). Core indicates lowermost occurrence (equivalent to Unit III of Severson and Hauck, 1990, 1997) is about 80 m thick in Wetlegs area and pinches out to southwest.

Ppcz Basal contact zone—Taxitic, medium- to coarse-grained, decussate, ophitic to subophitic olivine gabbro to augite troctolite; gabbroic pegmatite patches. Generally 55–75% tabular plagioclase ($An_{65–52}$), 15–30% granular to ameboidal to subpoikilitic olivine ($Fo_{61–53}$), 5–25% ophitic to subophitic augite ($En_{75–67}$), rare to 5% Fe-(Cu-Ni) sulfide, 1–3% subpoikilitic Fe-Ti oxide, 1–5% biotite, and minor amounts of apatite, other accessory minerals. Near basal contact and in vicinity of hornfels inclusions, rock grades to gabbronorite to norite. Zone rarely exposed but established from core as main sulfide-bearing unit, correlative with Unit I of Severson and Hauck (1990, 1997). Hornfels inclusions of the Virginia Formation (**Pvag**), which forms much of footwall, locally abundant; hanging wall inclusions of mafic volcanic hornfels present but rare. Top of unit in core generally marked by persistent layer(s) of melatroctolite (map unit **Ppmt**).

ANORTHOSITIC SERIES—Subsuite of Duluth Complex composed predominately of plagioclase cumulates displaying complex internal structure and lacking obvious signs of in-situ differentiation. Though emplaced in multiple intrusive events, individual intrusive bodies difficult to discern. Field relationships indicate anorthositic-series rocks generally are older than most rocks of layered series, though U-Pb ages suggest both series were emplaced about 1099 Ma (Paces and Miller, 1993). In the Allen quadrangle, anorthositic-series rocks present in two large areas underlying large volcanic hornfels bodies, and as isolated inclusions in Partridge River troctolite units.

Patg **Leucocratic troctolite to gabbro**—Lithologically variable unit. Modal composition: leucocratic to anorthositic (Pl 75–90%; $An_{66–55}$) and olivine gabbroic to troctolitic. Texture: medium coarse to coarse grained, poorly to well foliated, subophitic to ophitic, and poikilitic to granular in olivine ($Fo_{63–50}$) habit. Rock units are distinguished from similar rocks in the Partridge River intrusion by generally being coarser grained, more consistently leucocratic, more commonly altered, and by displaying commonly steep and disconformable foliation with regional internal structure. As typical of anorthositic-series rocks in Complex (Miller and Weiblen, 1990), lithologic and structural variations on outcrop scale are common. In places, sharp disconformable contacts between olivine leucogabbro and enclosing troctolite are exposed or inferred (e.g., outcrops in NE¼, sec. 1, T. 58 N., R.14 W.); more commonly, contacts with surrounding rocks are not exposed or are unclear.

Papt **Poikilitic leucotroctolite**—Homogeneous, medium-grained, decussate to moderately laminated, poikilitic leucotroctolite containing 1–4-cm olivine oikocrysts. Rock type occurs in similar settings as map unit **Patg**; considered subunit of that general grouping of anorthositic-series rocks. Distinguished from similar-appearing medium-grained poikilitic troctolites of the **Pppt** map unit by structural discordance with adjacent troctolites and lack of lateral continuity.

MISCELLANEOUS INTRUSIVE ROCKS—Includes rock units that cannot be assigned to other series of Duluth Complex.

Pmou **Oxide ultramafic intrusions**—Coarse-grained to pegmatitic clinopyroxenite, peridotite, and dunite enriched in Fe-Ti oxide; lesser amounts of melatroctolite and olivine melagabbro, and some areas of massive oxide. Oxide content (ilmenite and magnetite), 15–100%. Minor amounts of orthopyroxene, biotite, plagioclase ($An_{77–50}$), calcite, and sulfide. Though poorly exposed, several pluglike bodies, informally named Longnose, Longear, and Section 17 (Severson and Hauck, 1990, 1997), have been identified through exploration drilling. All are irregularly shaped and have sharp intrusive (but unchilled) contacts against enclosing troctolitic rocks of troctolite map unit (**Ppt**). Most bodies, though uncut by faults, are along major faults or at fault intersections, thus indicating their late and structurally controlled emplacement.

Pmog **Olivine gabbro**—Coarse-grained, decussate to poorly laminated, subophitic to intergranular, apatitic, oxide-rich olivine gabbro to olivine-poor oxide gabbro. Composed of 60–75% plagioclase ($An_{60–36}$), 0-10% granular to subpoikilitic olivine ($Fo_{51–39}$), 15–30% subophitic to subhedral granular augite ($En_{73–62}$), 5–10% subpoikilitic Fe-Ti oxide, and 0.5–2% prismatic apatite. Intrusive (and chilled) into volcanic hornfels and anorthositic rocks (map unit **Patg**); contact relationships with troctolite unclear. Unit probably correlative with Powerline Gabbro of Bonnichsen (1974) east of Allen quadrangle. Though Bonnichsen (1974) suggested that the gabbro is possibly related to the Partridge River intrusion, transition from troctolite to gabbro in the Allen quadrangle seems too abrupt to be result of progressive, in-situ differentiation.

Pmt **Troctolite**—Homogeneous, medium-grained, moderately laminated, intermittently layered, ophitic augite troctolite. Rock type known from a few exposures in southeastern corner of quadrangle; extrapolated from aeromagnetic signature to intrude map units **Patg** and **Pnmh**. May correlate with troctolitic rocks of Partridge River gabbro complex described to the east (TCG unit of Severson and Hauck, 1990). Relationship of unit to troctolitic rocks of physically separated but lithologically similar Partridge River intrusion is unclear.

Pmfi **Footwall intrusion**—Fine-grained, black basalt forming one-m-thick sill within K submember (Upper Cherty member) of Biwabik Iron Formation (unit **Pbif**). Generally, 50% plagioclase laths, 10% ilmenite blades, 40% altered groundmass (fibrous mixture of chlorite, hornblende, and sericite), and accessory Fe-Cu sulfides and apatite. Unit chemically similar to another sill within C submember of Biwabik Iron Formation northeast of Allen quadrangle (Severson and Hauck, 1997).

Pmhb **Hornblendite**—Medium-grained rock; 85–95% subhedral to euhedral hornblende and 5–15% microcrystalline groundmass; varying amounts of feldspar, quartz, sericite, and hornblende. Present only in two outcrops immediately west of Siphon fault; forms subhorizontal lense intrusive in Archean metasedimentary rocks. Thought to be Mesoproterozoic owing to chemical and mineralogical similarity to hornblende-rich granitic rocks intruding troctolitic rocks near Grano fault, northeast of Allen quadrangle (Severson and Hauck, 1997).

NORTH SHORE VOLCANIC GROUP—Thick (3–7 km) sequence of tholeiitic plateau lava flows and minor interflow sedimentary rocks deposited during formation of Midcontinent rift. Volcanic edifice forms hanging wall to most of Duluth Complex. Remnants of lower part of sequence in Allen quadrangle form isolated mafic hornfels inclusions of varied size.

Pnvh **Volcanic hornfels**—Fine-grained, granoblastic to poikiloblastic basaltic hornfels; consists of variable amounts of plagioclase, augite, olivine, hypersthene, and inverted pigeonite. Typically, all phases granular; locally, some possible poikilitic mafic minerals. Both massive and meta-amygdaloidal varieties present; latter characterized by knots of plagioclase standing out in relief. Also present as inclusions of varied size in lower part of Partridge River intrusion. Oxide-poor composition of hornfels inclusions implies volcanic protoliths of more primitive (high mg#) olivine tholeiitic composition.

Pnmh **Magnetic volcanic hornfels (Colvin Creek type)**—Fine- to very fine grained, massive to rarely meta-amygdaloidal, granoblastic to poikiloblastic oxide-rich basaltic hornfels. Composed of 40–65% granular plagioclase, 10–40% granular augite, 0–10% granular to poikilitic orthopyroxene, 0–20% granular to poikilitic olivine, and 5–15% composite grains of granular magnetite and ilmenite. Most rocks are moderately to strongly magnetized and generate strong aeromagnetic anomalies. Oxide enrichment suggests volcanic protoliths of more evolved (low mg#) Fe-Ti tholeiitic composition. Exposures in quadrangle form southwestern continuation of large Colvin Creek inclusions noted by Bonnichsen (1972, 1974), Tyson (1976), Severson and Hauck (1990), and Patelke (1996) in Babbitt SW quadrangle.

Pnsh **Sedimentary hornfels (Colvin Creek type)**—Very fine grained, bedded to cross-bedded mafic hornfels. Present within Colvin Creek basaltic hornfels (map unit **Pnmh**) in a few outcrops; similar rocks common to east (Severson and Hauck, 1990). Protolith interpreted as metamorphosed volcanogenic (interflow) sandstone (Patelke, 1996).

PALEOPROTEROZOIC

ANIMIKIE GROUP—Supracrustal sequence of clastic and chemical sedimentary rocks deposited on continental margin of Superior craton in foredeep basin during latter stages of Penokean orogeny.

Pvag **Virginia Formation**—Well-bedded sequence of argillaceous siltstone, carbonaceous shale, mudstone, fine-grained feldspathic graywacke, and minor limey-cherty interbeds. Owing to sparse outcrop in quadrangle, information on Virginia limited to core. Fine-grained sedimentary rocks encountered by drilling in immediate footwall of Complex display intense granoblastic recrystallization and ductile deformation.

Pvga Graphitic argillite—Informal member of Virginia Formation. Variable amounts of pyrrhotite created by metamorphism of carbonaceous shale by Duluth Complex magma.

Pbif **Biwabik Iron Formation**—Well-bedded, iron-bearing strata of alternating cherty intervals (thick bedded; granular; rich in quartz and iron oxides) and slaty intervals (finely laminated; fine grained; generally rich in iron silicates and iron carbonates). Only minor thermal-metamorphic effects in iron-formation, but strong recrystallization where intersected by drilling in Duluth Complex footwall.

Ppqj **Pokegama Quartzite**—Well- to cross-bedded quartz arenite; local quartz- and granite-pebble conglomerate lenses. Thin patchy veneer between Biwabik Iron Formation and granitic rocks of Giants Range batholith. Conglomeratic beds near Siphon fault contain red, blocky, poorly indurated, hematitic fragments.

ARCHEAN

GIANTS RANGE BATHOLITH—A multiply intruded complex of granitic rocks emplaced in supracrustal rocks of Wawa subprovince of Superior Province.

Aggr **Granitic rocks**—Coarse-grained, massive quartz monzonite to granite; local hornblende syenite and gneiss.

SUPRACRUSTAL ROCKS OF WAWA SUBPROVINCE—Moderate- to low-grade metavolcanic and metasedimentary rocks south of the Vermilion Fault.

Awag **Meta-argillite and graywacke**—Well-bedded sequence of graywacke and argillite metamorphosed to greenschist facies; local reworked tuff interbeds. Higher metamorphic-grade equivalents near Giants Range batholith. Well-developed cleavage; bedding planes moderately to well preserved; graded bedding rarely observed. Steeply plunging, tight folds present locally.

Awmv **Mafic metavolcanic rocks**—Mafic igneous rocks interpreted from geophysical data (Chandler and Lively, 1998) as present in subsurface south of Archean exposure. Shown only on cross section.

Awvc **Intermediate volcaniclastic rocks**—Pale-green, fine- to medium-grained, pitted outcrops of andesitic crystal tuff and crystal-lithic tuff; locally interbedded with meta-argillite and graywacke (map unit **Awag**). Unit mostly massive-bedded tuff and reworked tuff; variable amounts of subhedral to euhedral hornblende. At the western edge of the quadrangle, the unit has as much as 15% hornblende-rich lithic fragments (1–20 cm) exhibiting wide range in shape from lensoidal with highly irregular edges to equant to subrounded.

Awss **Siliceous sediment**—White, extremely fine grained, siliceous rock at base of intermediate volcaniclastic rocks (map unit **Awvc**) and within meta-argillite and graywacke (map unit **Awag**).

Geologic contacts.

Approximately located from outcrops and drill holes.

Inferred from indirect evidence (aeromagnetic data, topography, and structural projections).

Faults.

U D Approximately located from outcrops and drill holes; U, upthrown side, D, downthrown side.

Inferred from indirect evidence (aeromagnetic, topographic, and photographic lineaments).

Speculative or hypothetical.

Outcrop or generalized area of small outcrops.

Drill hole.

Copper-nickel sulfide deposit in the basal contact zone of the Duluth Complex (map unit **Ppcz**)— Identified from drill core and projected to surface (see cross section). Smaller dots on the map indicate the deposit dips beneath units overlying **Ppcz**.

Strike and dip of planar features.

To improve clarity, the symbols shown on the map have been reduced in number. The complete set is available as part of the Minnesota Geological Survey GIS package.

15 Volcanic or sedimentary bedding—Inclined; vertical; horizontal.

15 Igneous modal or textural layering—Inclined; vertical; horizontal.

15 Igneous foliation—Inclined; vertical; horizontal.

15 Metamorphic foliation—Inclined; vertical.

15 Intrusive igneous contact—Inclined; vertical.

15 Joints—Inclined

15 Joints or fractures with wall-rock alteration showing minor slippage of mineralized coatings—Inclined; vertical; horizontal.

15 Dikes—Inclined; vertical.

Bearing and plunge of linear features.

15 Lineation formed by igneous mineral fabric.

15 Lineation formed by elongate clasts of fragmental rock.

Strike of igneous fabric.

ACKNOWLEDGMENTS

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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 gude engineering-scale decisions without site-specific verification.